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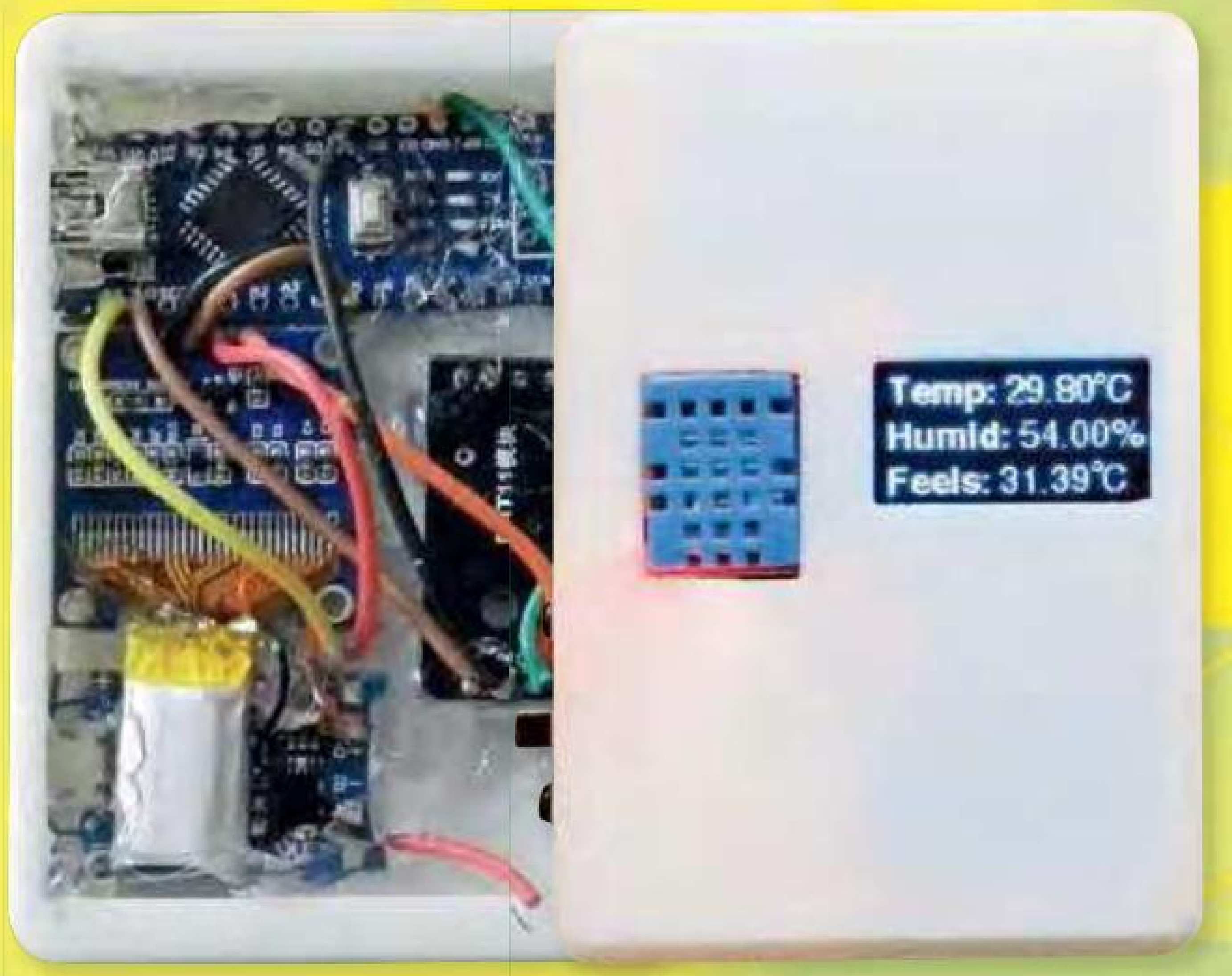
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Practical Electronics

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November 2022
ISSN 2632 573X

Contents

Automatic USB Cable Tester
USB-A
USB-C
Downstream Facing Ports
USB-B
USB-C
Micro-B
Mini-B
Upstream Facing Ports

ATT=-21.75DB
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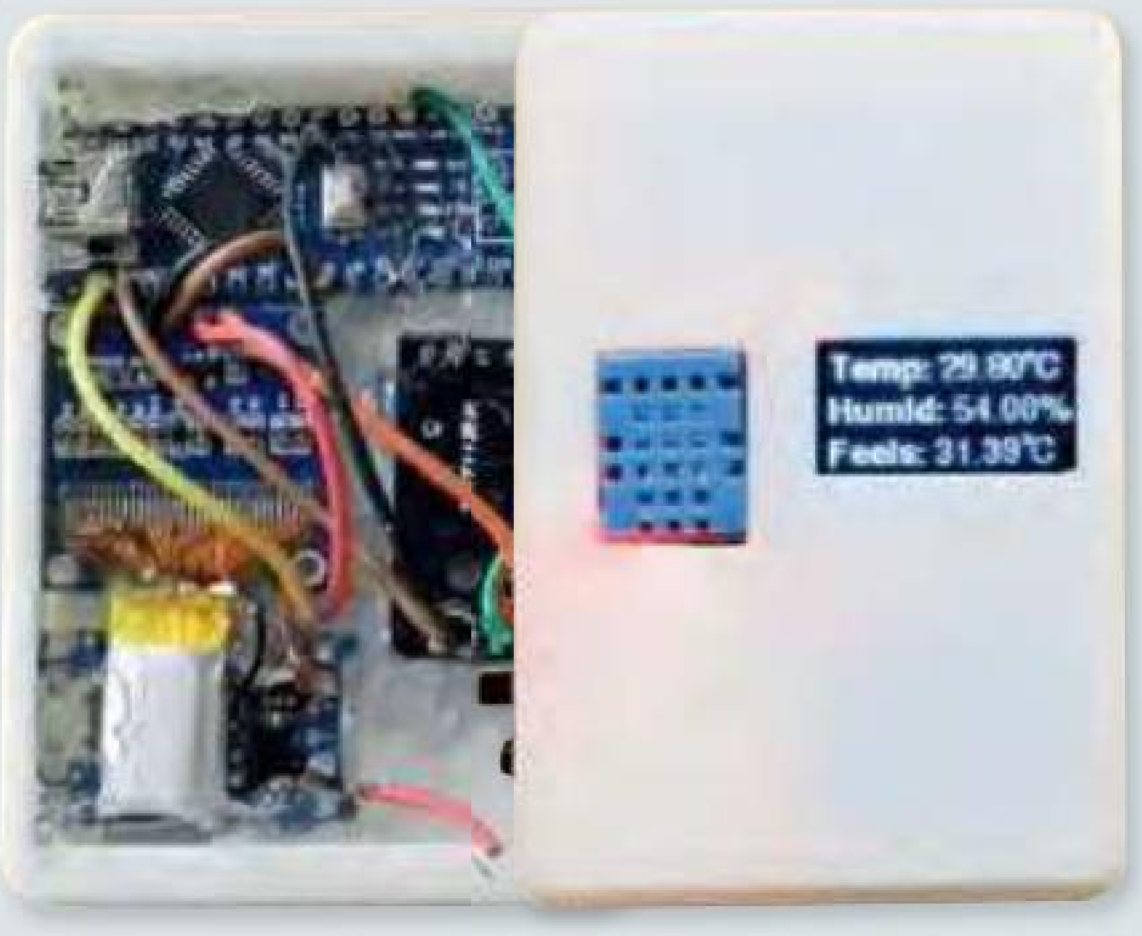

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The December 2022 issue of *Practical Electronics* will be published on Thursday, 3 November 2022 – see page 72.

Projects and Circuits

USB Cable Tester – Part 1 by Tim Blythman 16
Here is an easy way to test all manner of USB cables; this USB Cable Tester is so handy, we think you will find it indispensable!

Pocket Weather Station by Aarav Garg 26
This is an excellent beginners' project that uses five modules to make something useful – a mini weather station you can carry everywhere with you.

Model Railway Carriage Lights by Les Kerr 30
These model train carriage lights (designed for OO-gauge) are battery-powered and can be switched on and off with an external magnet.

Self-Contained 6GHz Digital Attenuator by Jim Rowe 34
This programmable module attenuates signals from 1MHz to 6GHz by 0 to 31.75dB in 0.25dB steps. Control is via five small switches and a tiny OLED.

Series, Features and Columns

Techno Talk by Mark Nelson 8
Hidden hazards

The Fox Report by Barry Fox 10
Be careful what (new tech) you wish for

Net Work by Alan Winstanley 12
A round-up of topical technological issues and trends from the UK and around the world – from the Queen's first email to nuclear power.

Make it with Micromite by Phil Boyce 37
Part 41: Self-contained PicoMite computer

Audio Out by Jake Rothman 42
Transformers in audio – Part 4

Circuit Surgery by Ian Bell 51
Electronically controlled resistance – Part 3

Electronic Building Blocks by Julian Edgar 57
Selecting and Using Actuators – Part 2

Max's Cool Beans by Max The Magnificent 62
Flashing LEDs and other engineering temptations – Part 33

Regulars and Services

Wireless for the Warrior 2
Subscribe to Practical Electronics and save money 4
NEW! Practical Electronics back issues DOWNLOADS – 2021 now available! 6
Reader services – Editorial and Advertising Departments 7
Editorial 7
Cables… Missing pages… PCBs!
Exclusive Microchip reader offer 9
Win a Microchip AVR-IoT Cellular Mini
PE Teach-In 9 24
PE Teach-In 8 33
Teach-In bundle – what a bargain! 56
Practical Electronics PCB Service 68
PCBs for Practical Electronics projects
Classified ads and Advertiser index 71
Next month! – highlights of our next issue of Practical Electronics 72

WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

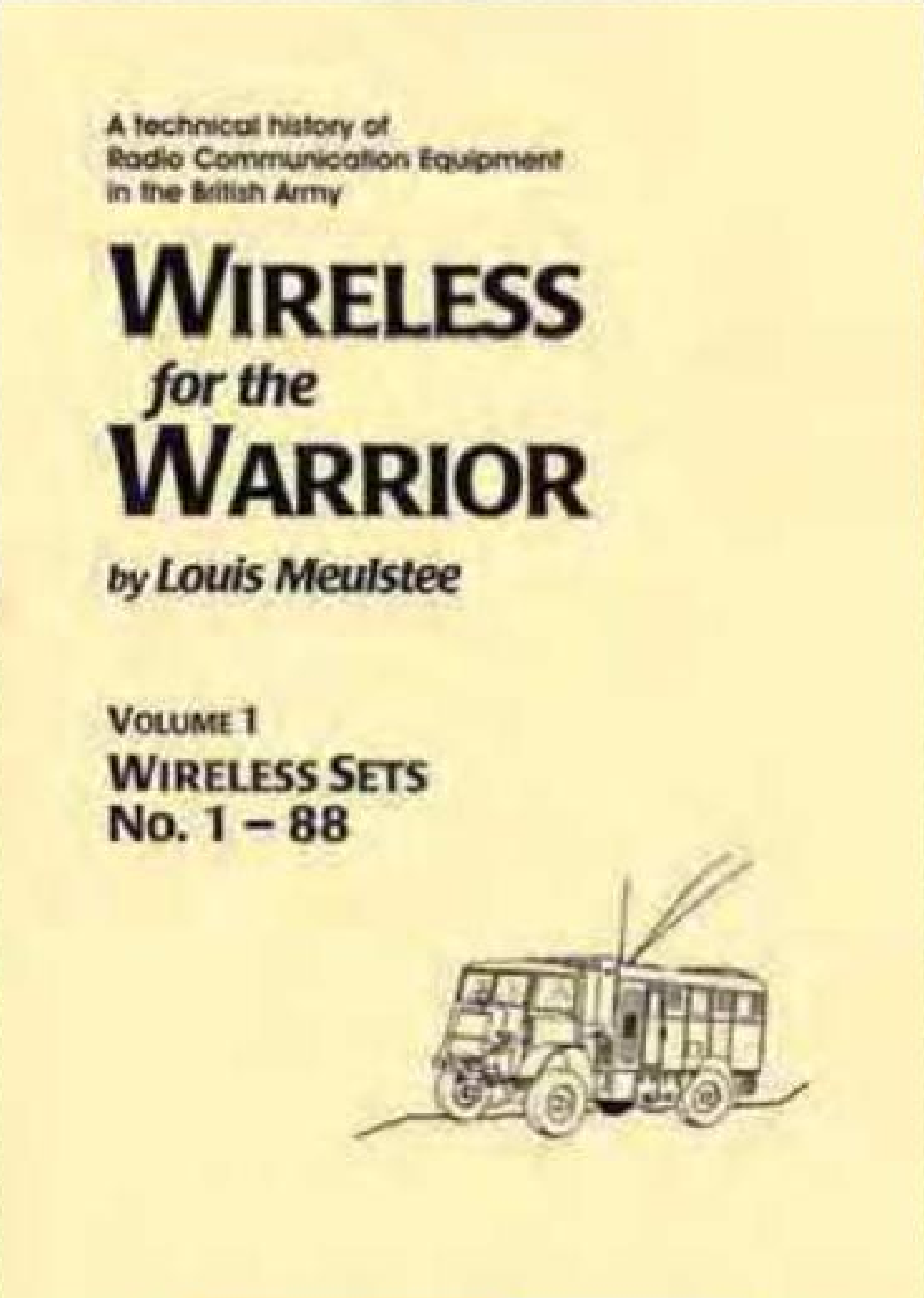
The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.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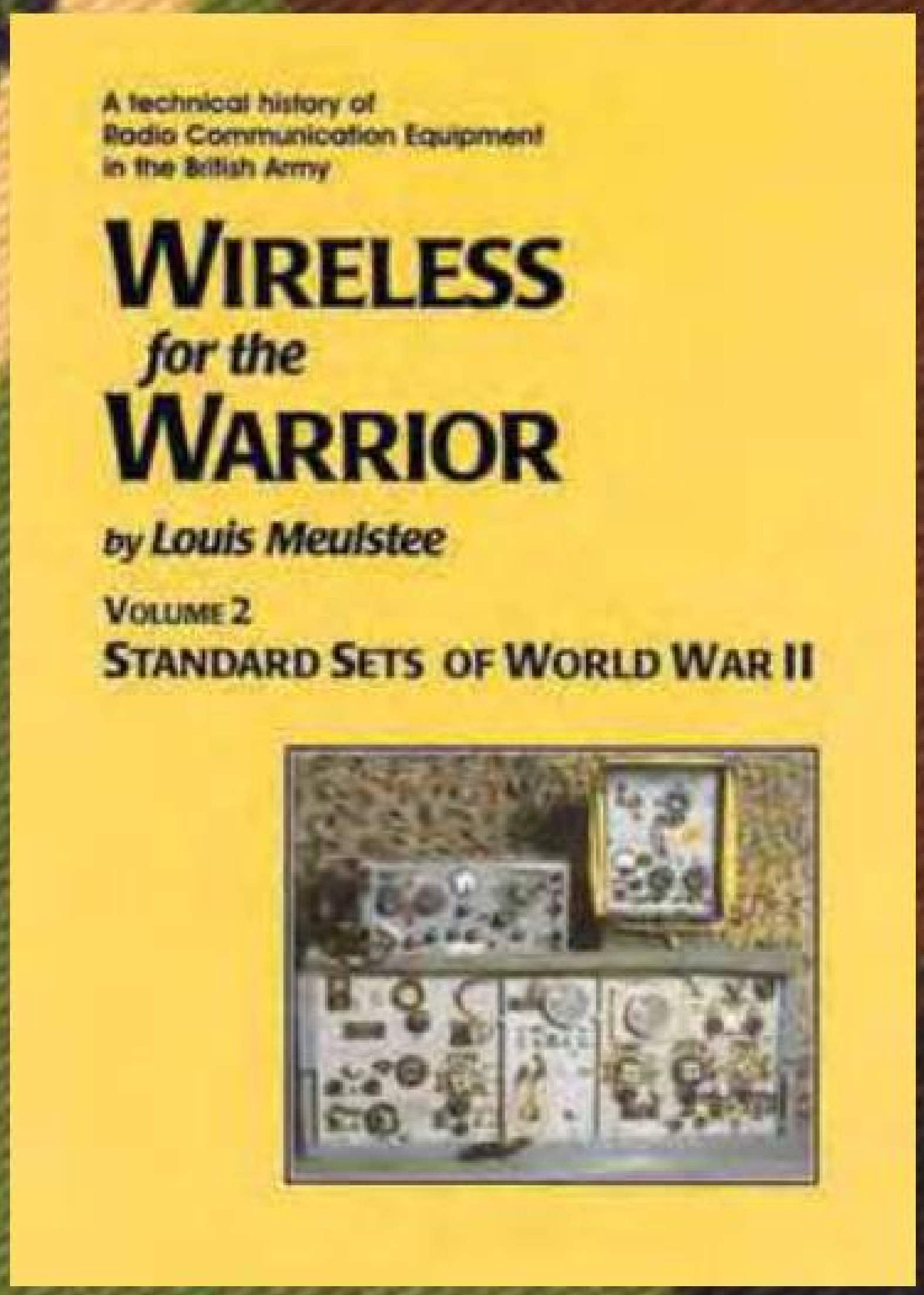
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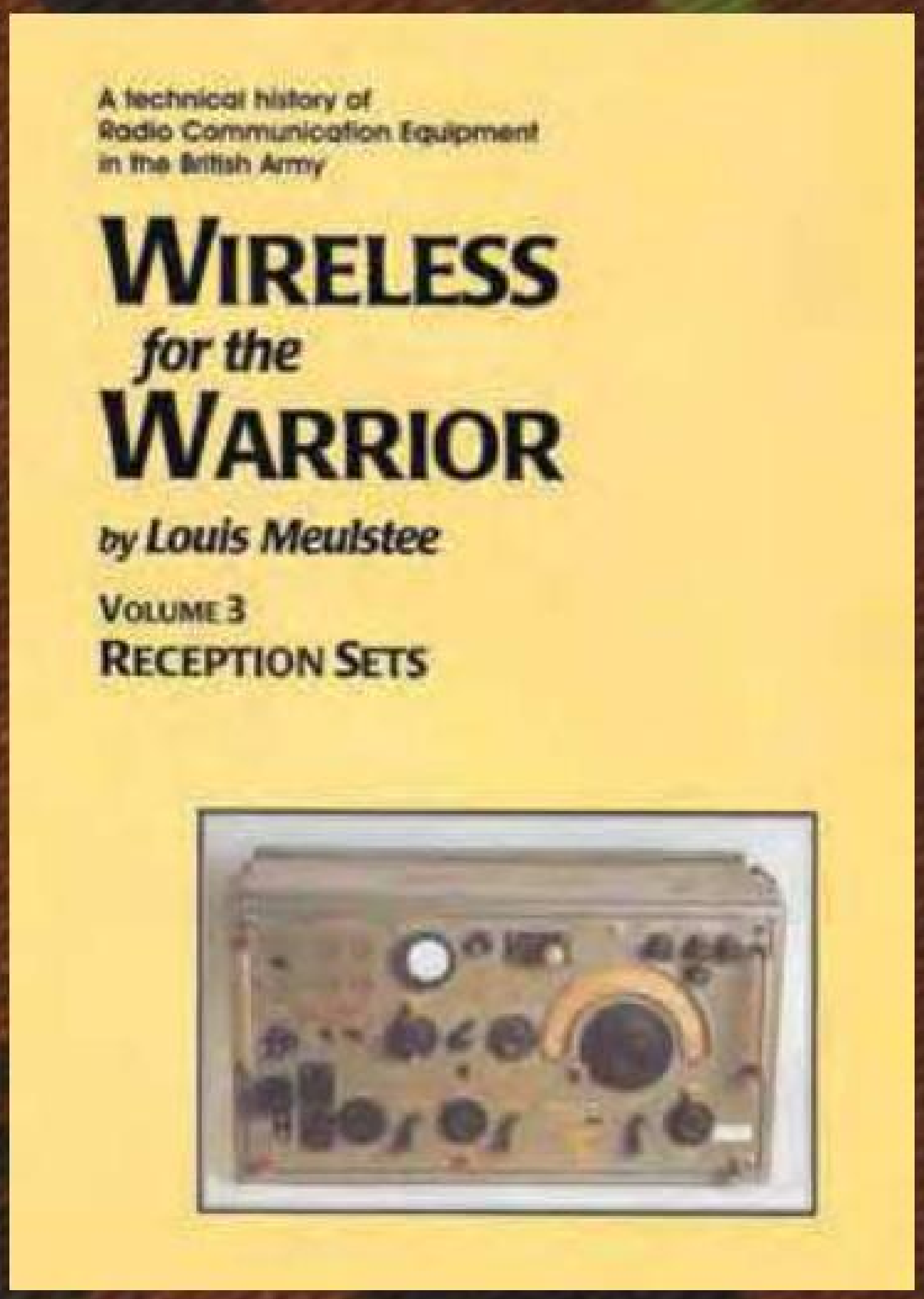
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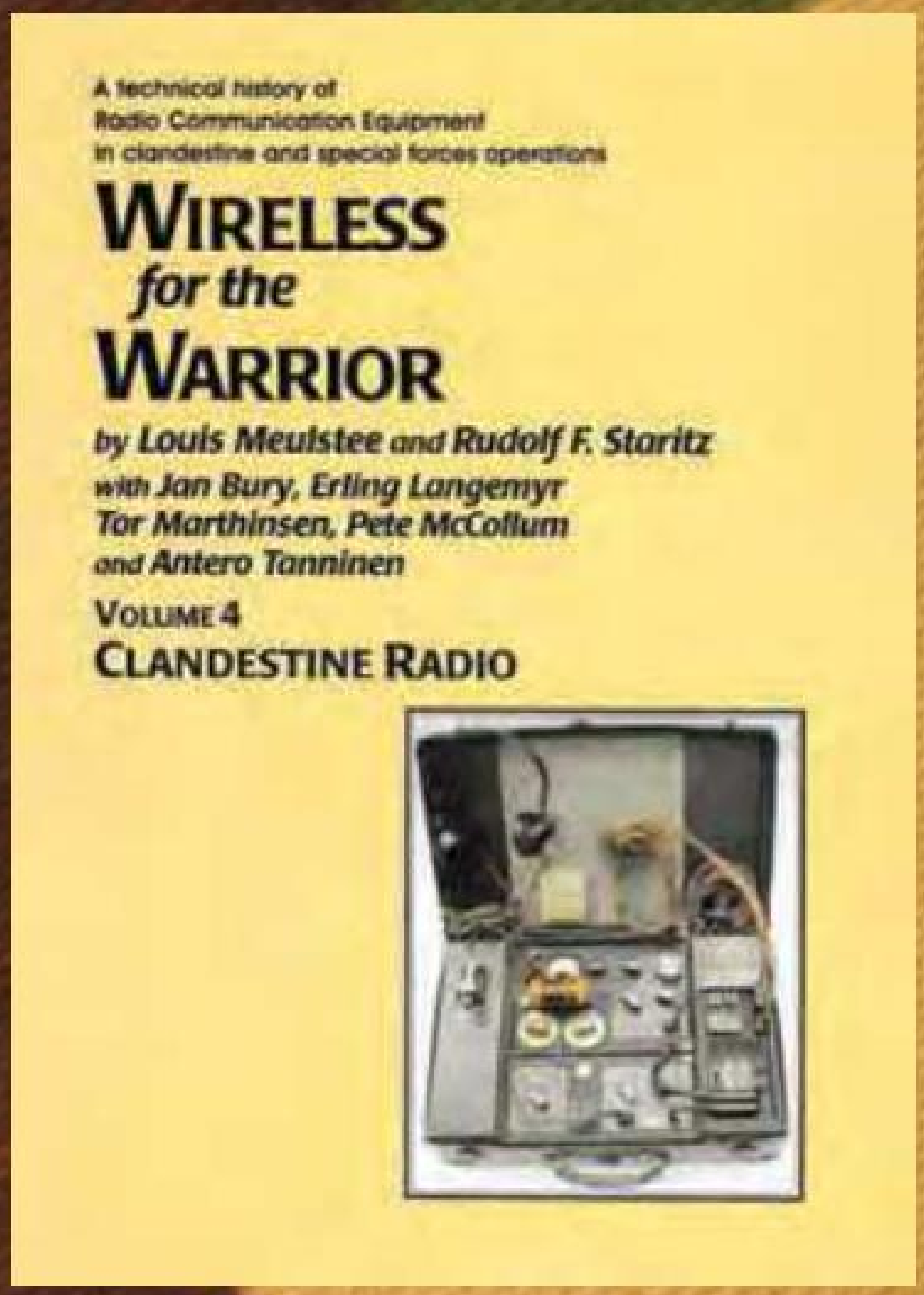
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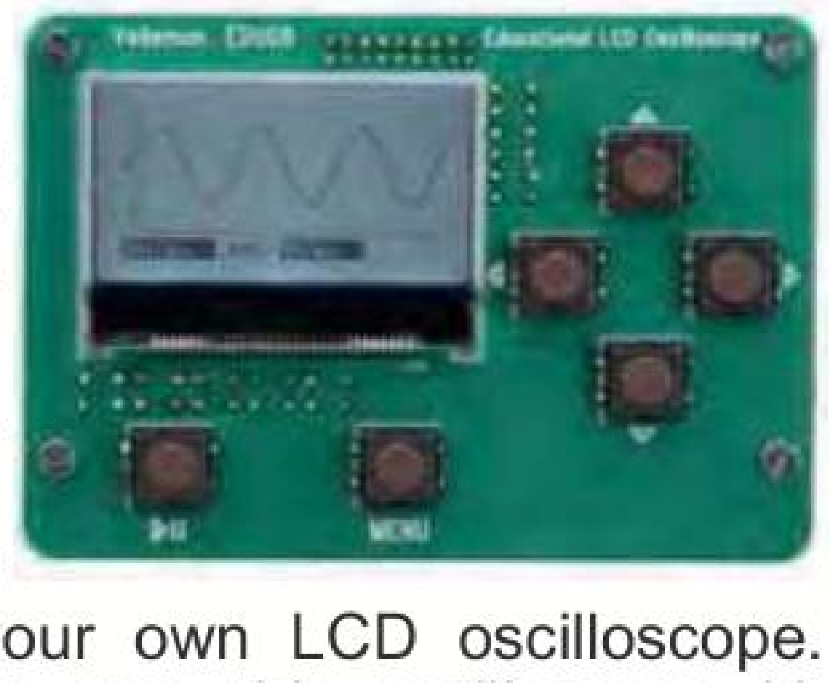

Build your own LCD oscilloscope with this exciting new kit. Learn how to read signals. See the electronic signals you learn about displayed on your own LCD oscilloscope. Despite the low cost, this oscilloscope kit has a lot of features found on expensive units like signal markers, frequency, dB, true RMS readouts and more. A powerful auto-setup function will get you going in a flash!
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Electron Publishing Limited **Mob** 07973 518682
1 Buckingham Road **Fax** 01202 843233
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Advertisement offices

Practical Electronics Adverts **Tel** 01273 777619
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Editor Matt Pulzer
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Digital subscriptions Stewart Kearn **Tel** 01202 880299
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Projects and circuits

All reasonable precautions are taken to ensure that the advice and data given to readers is reliable. We cannot, however, guarantee it and we cannot accept legal responsibility for it.

A number of projects and circuits published in *Practical Electronics* employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD (GFCI) adaptor.

Component supplies

We do not supply electronic components or kits for building the projects featured, these can be supplied by advertisers. We advise readers to check that all parts are still available before commencing any project in a back-dated issue.

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Editorial

Cables

Some of our projects are just for fun or to support another hobby, some projects help you enjoy superb audio quality which might otherwise be too expensive to access, and some of our projects are ingenious devices that help you keep your electronics show on the road. Our main project this month is very much in the latter category.

You can picture the scene; a useful piece of equipment has failed and resists all efforts to recover. We've all been there, and sooner or later we start to wonder if the problem is with the actual equipment or just the cable it's connected to. Perhaps there is a replacement in the ever-growing box of cables kept for just this occasion. But is the old cable any good? Perhaps not… so what to do? Well, now you can quickly and easily test the most common types of cable – the various incarnations of the ubiquitous Universal Serial Bus cable, more commonly known as just a 'USB cable'.

So, step forward the *USB Cable Tester*. It will check just about any USB cable: USB-A (2.0/3.2), USB-B (2.0/3.2), USB-C (3.2), Micro-B (2.0/3.2) and Mini-B (2.0). It will even report short circuits, open circuits and other faults.

In electronics, few things can be more frustrating than troubleshooting, so anything that reduces the pain is truly welcome. This handy device will quickly and efficiently help you eliminate a common source of problems – thoroughly recommended!

Missing pages

We had a production problem last month and a few issues went out with missing pages. We think we caught most of them before distribution, but if one slipped through and you received it then do please let us know and we will of course replace it.

PCBs

We've had some PCB shortages recently but have now restocked, and the online shop is fully up to date, especially with recent boards. So, as the nights draw in, now is the perfect opportunity to start planning some autumn and winter projects.

Matt Pulzer
Publisher

Hidden hazards

Techno Talk

Mark Nelson

A number of the substances (mainly fluids) that we use in our workshop for constructing new projects, or refurbishing old test equipment and other appliances, are dangerous – in fact, potentially toxic or even carcinogenic. Harmful either to ourselves or to the equipment. Carry on reading if you want to know the risks you may be taking.

Electricity is not the only hazard that lurks in the workshop. It's funny (but only in an ironic kind of way) how many of the things we used to do are now considered highly dangerous. When I was a student, 'Trike' (trichloroethylene) had only just replaced good old 'Carbon Tet' (carbon tetrachloride) as the go-to solvent that would get the muck out of everything. Now it's taboo. It was only recently that DIY shop paint and varnish removers contained methylene dichloride (alias dichloromethane or DCM), which is now listed as a Class Three carcinogen 'with the possible risk of irreversible side effects'. As well as leading to nausea and drowsiness, it is a powerful skin irritant, meaning that you had to wear rubber gloves and ensure good air ventilation when using these stripper products. Unlike cats, we get only one life, so we have to use safer methods these days.

Cleaning materials and polishes

Some household products are more harmful to our treasured equipment than to us human beings! For example, combined cleaning and polishing liquids containing silicone or solvents can be hazardous to certain plastics. They can cause 'stress corrosion cracking' in some thermoplastic materials. Armor-All (sold at Halfords and Wilko for instance) is a form of silicone oil dissolved in a mixture of solvents. It is fine for use on polyvinyl chloride (PVC) but can cause problems with ABS (acrylonitrile butadiene styrene, a common thermoplastic polymer) used in some radios, test gear and telephones. For refreshing clear plastic dials and meter faces you are safer using something much milder to clean them, but if strong solvents are essential, then use these carefully and rinse off as quickly as possible.

Noxious fumes and common sense

I confess I rather like the smell of hot resin-cored solder (rosin-cored sodder if you are American) as it smokes and sizzles, but I really shouldn't. Better to buy a cheap bench-top extractor fan online that disperses the fumes to the far side of the room. But is soldering really so harmful? It can be, yes. Soldering with lead (which many of us still do) can produce dust and fumes that are hazardous. In addition, using flux containing resin or colophony produces solder fumes that, if inhaled, can result in occupational asthma or worsen existing asthmatic conditions; as well as causing eye and upper respiratory tract irritation.

Another commonplace irritant is the liquid solvent used for chemically 'welding' acrylic sheet to make cases for test gear and other projects. Plasweld is one of the brand names and it goes also by the name of methyl ethyl ketone (MEK) and butanone. It works like a treat, which is why it is also used to weld PVC electrical conduit pipes. Industrial uses include degreasing oils and lubricants, also to clean up certain adhesives, lacquer and latex paints. You must, however, provide good ventilation. As well as being a fire risk (highly flammable), MEK irritates the skin, causes dizziness, light-headedness, headache, nausea, blurred vision, and may cause you to pass out. Repeated high exposure can damage the nervous system and may affect the brain. It's not just us that it attacks – MEK will also degrade and discolour most plastics, especially if exposed for a long period of time.

More traps for the unwary

Many people swear by WD-40, advertised as 'the can with thousands of uses: a penetrating oil, lubricant, cleaner, degreaser or solution to protect against or remove rust'. But read the small print on the website and you will also see: 'Many of the uses of WD-40 products described on our company websites were provided to WD-40 Company by end-users of the products, and do not constitute recommendations or suggestions for use by WD-40 Company. These uses have not been tested by WD-40 Company. Consumers should exercise common sense whenever using WD-40 Company products.' Too jolly well right!

WD-40 is a product to use with great care. The version sold in aerosol cans is 90% flammable liquids and gas plus 10% of a proprietary corrosion inhibitor. Its original purpose was only as a water-displacing compound (that's what the 'WD' in the name stands for). The kerosene in it gives it a low surface tension, which allows it to penetrate small cracks and crevices. Once this kerosene has evaporated, the oil is left with a little corrosion inhibitor. Although the oil has some limited lubricating properties, it also acts as an insulator and does nothing to clean oxidised switch contacts. WD-40 does indeed protect a surface from corrosion and oxidation, but it achieves this by physically covering it. And like all paraffinic oils, it reacts slowly with oxygen in the air to cross-link and polymerise, producing the well-known 'gummy mess'.

It is important to be aware that WD-40 is not plastic-friendly. Until recently, the company's own website warned that it attacks polycarbonate and clear polystyrene plastic, but now gives only a short list of plastics on which WD-40 is safe to use. On the Web there are many reports of it causing other plastic materials to crack or crumble. As the action is not immediate, the effects are seen not seen until the damage has already been done.

PCBs warning

No, not 'printed circuit boards' but polychlorinated biphenyls, which are highly carcinogenic chemical compounds formerly used in industrial and consumer products. You are very unlikely to encounter them nowadays unless you repair elderly television receivers and video monitors. They have a nasty tendency to seep out of high-voltage capacitor cans and cover the device's whole outer surface. If you are unwise enough to wipe away the greasy film with paper towels, you will find that it has returned a week later. Stay safe and have *nothing* to do with PCB capacitors.

Win a Microchip AVR-IoT Cellular Mini

Practical Electronics is offering its readers the chance to win a Microchip AVR-IoT Cellular Mini (EV70N78A) – and even if you don't win, receive a 15%-off voucher, plus free shipping for one of these products.

The AVR-IoT Cellular Mini is a development board based on the AVR128DB48 8-bit microcontroller (MCU). This solution provides a robust platform to start building sensor and actuator nodes on 5G narrowband IoT networks. The AVR-IoT Cellular Mini is a small-form-factor board making it an ideal solution for developers who want to connect IoT devices to an available 5G network. This is an essential feature for devices on the go or located in remote areas with limited availability of Long Range (LoRa) networks or other Low Power Wide Area Network (LPWAN) solutions.

Worth $60.00 (approx £49.99) each

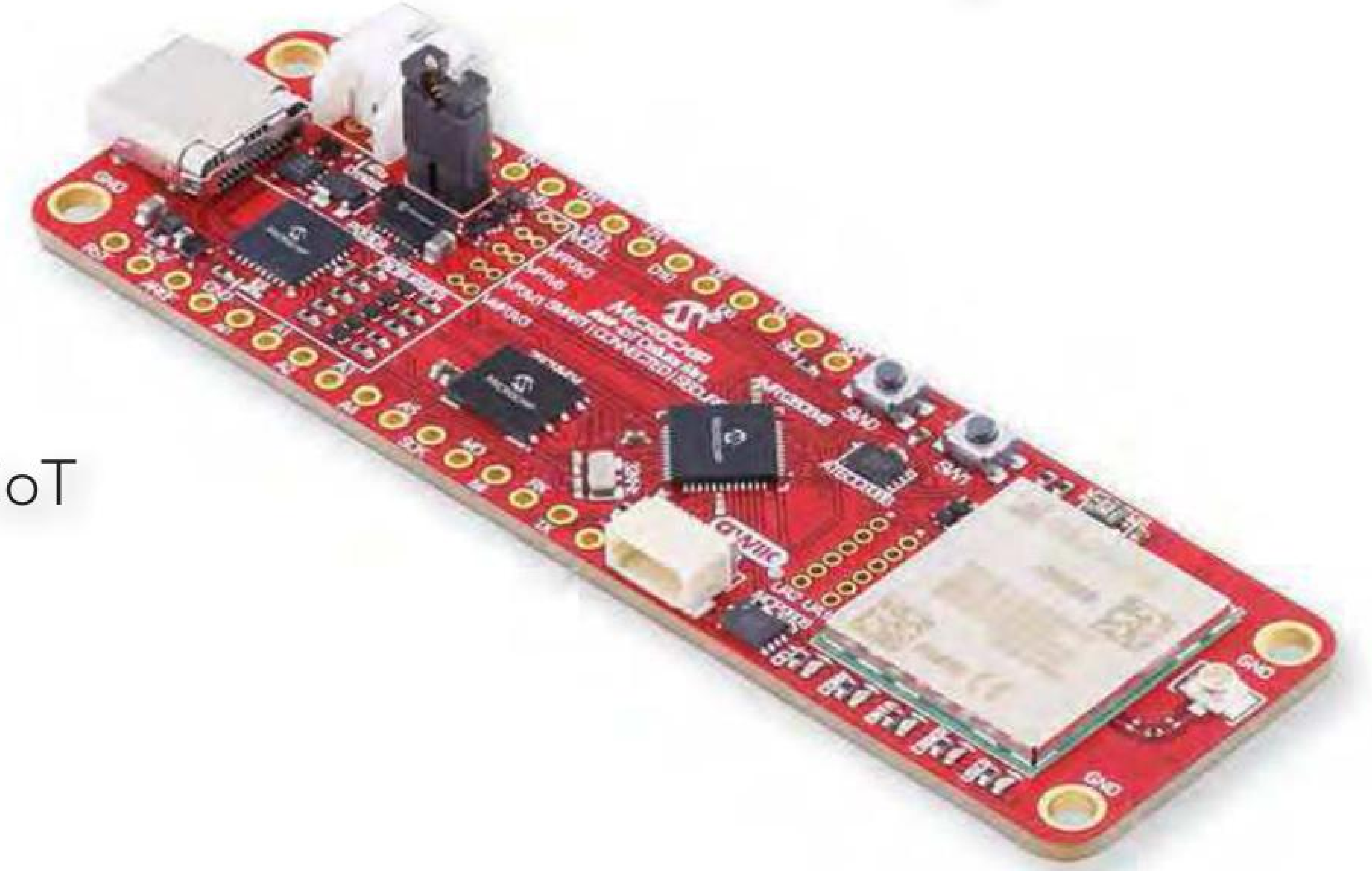
Customers can tap into the flexibility and ease of design offered in the latest AVR128DB48 8-bit MCU family, including security protection with Microchip's ATECC608 CryptoAuthentication device. The ATECC608 can easily be configured to most major cloud service providers through Microchip's IoT Provisioning Tool.

The AVR-IoT Cellular Mini comes pre-configured to send data from on-board light and temperature sensors to the cloud, viewable using Microchip's sandbox portal. The sandbox portal provides customers with the ability to track and monitor their device in real time from a remote location.

This functionality covers the core requirements of many applications in various industries, including agriculture, industrial and energy, as well as consumer spaces such as transportation of goods, alarm systems, building automation and remote monitoring.

To provide an even easier, more efficient and cost-effective solution for developers to connect IoT devices to 5G using the AVR128DB48, Microchip partnered with Sequans to include its Monarch 2 GM02S single-chip radio equipped with 5G LTE-M and narrowband IoT. Microchip also partnered with Truphone to provide the SIM card for cellular service that offers reliable coverage worldwide.

Free-to-enter competition



Microchip AVR-IoT Cellular Mini

Microchip EV70N78A

How to enter

For your chance to win a Microchip AVR-IoT Cellular Mini or receive a 15%-off voucher, including free shipping, enter your details in the online entry form at:

https://page.microchip.com/PE-Mini.html

Closing date

The closing date for this offer is 31 October 2022

July 2022 winner

Vincenzo Dello Iacovo

He won a Microchip SAM C21 Xplained Pro Evaluation Kit

The **Fox** Report

Barry Fox's technology column

Be careful what (new tech) you wish for

The UK's identity card scheme was scrapped in 2011 and fierce campaigning blocked the introduction of a more modern electronic/biometric system – as used in many countries. The arguments for and against a secure, dedicated ID card are many and divisive: would it cut crime but infringe on civil liberties, interfere with both legitimate and illegitimate migration and asylum, save or cost taxpayers money? No one can accurately predict, although the history of large, government-backed IT systems is to say the least patchy – just ask the NHS or Royal Mail branch managers.

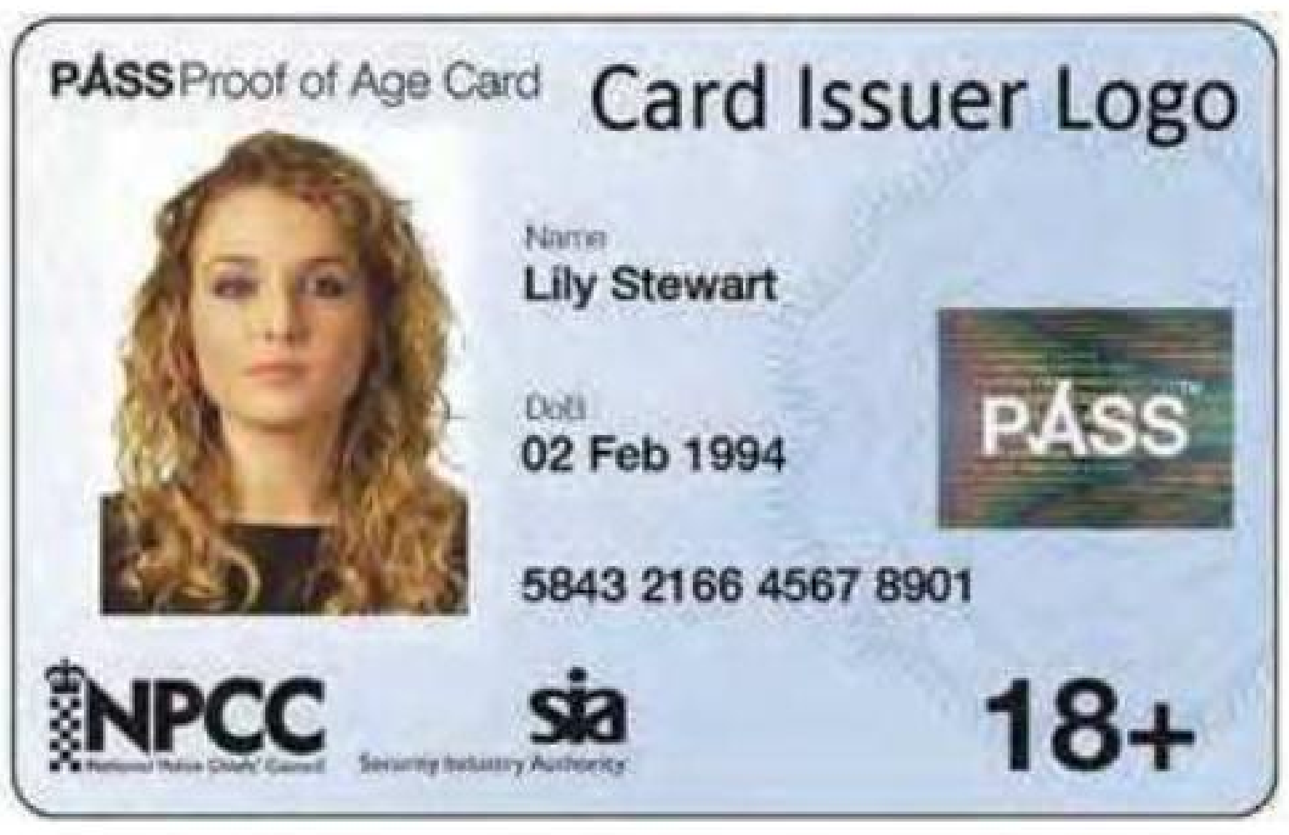
Can you prove who you are?

But one thing is now becoming clear; the lack of an all-purpose modern-tech ID card means that some matters of everyday life in the UK now depend on being able to offer one of three alternatives: a valid photo driving licence, a valid passport or a young person's PASS (Proof of Age Standards Scheme). This is an ID card scheme supported by the Home Office, the Chartered Trading Standards Institute (CTSI) and the National Police Chiefs' Council (NPCC). Its aim is to support retailers when supplying alcohol, tobacco, knives, fireworks, gambling, access to pubs/clubs and other age-restricted products and services by providing proof that customers are not below the legal purchasing age.

Although it's not well publicised, there is a version of the young person's 'old enough to drink' PASS photo-ID card which can be used to prove identity by older people who are clearly old enough to drink (details can be found here: **https://bit.ly/pe-nov22-id**) The '18+ Citizen Card' costs £15 (£30 if needed quickly) and lasts only three years. It can be a physical photo card, or digital ID phone app.

The above is not good news for anyone who is over 18, but who does not drive and does not travel abroad. Try, for instance, getting a faulty phone SIM replaced; high street dealers will only send them to customers who can prove their identity with a driving licence or passport. Other photo ID, such as library or travel passes, will not be accepted.

In North London, Camden Council recently made news by insisting on sight of a passport or driving licence before paying energy rebates and crisis benefits through Post Offices. It's estimated that 20% of those offered a rebate in April did not collect it, in many cases because they couldn't prove their identity. Other councils will very likely be pilloried for paying out to people without solid proof of who they are.



PASS Proof of Age Card

Card Issuer Logo

Name

Lily Stewart

DoB

02 Feb 1994

PASS

5843 2166 4567 8901

NPCC

sia

18+

The UK's PASS proof-of-age ID.

Stores, clubs, pubs and hotels routinely use generic electronic ID readers which cost a few hundred ponds. They hook up with a PC and do not need to go online and access any official database. They are used to confirm that the customer pictured on the card is who they say they are, how old they are and where they live. Gradually these readers are sliding, largely unseen, into more general use. Think carefully about this before letting a driving licence or passport lapse; it may be a difficult, lengthy process to get a new one, and in the meantime cause you real access and retail problems.

Is cash still king?

Think carefully, also, about welcoming the end of cash, and its replacement with cards and phone readers – as accelerated by the Covid crisis. I now find that often the only way to buy an ice cream or coffee is with a debit/credit card.

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Card readers rely on a mobile or Wi-Fi signal, which is no problem in towns and cities – except in a power cut of course. But out of town, in a field, park or the garden of a stately home, there will be no Wi-Fi available and cell phone coverage which is based on a few local residents chatting will collapse when an influx of show-goers and stalls are all trying to move money.

I spoke recently with one show organiser. The landowner where she was putting on a gardening show had asked for tens of thousands of pounds to provide Wi-Fi. The cellphone companies were not interested in installing a temporary cell tower, as is now routinely done at large music festivals. Cellphone coverage was decidedly iffy.

Thinking ahead she advised all pre-registered visitors to bring cash. Those who did not were offered the chance to get cash-back on any purchase they made from any card readers on the show ground – provided they managed to connect. Older, slower readers, with a GSM/GPRS roaming SIM that locks on to the strongest cellphone signal available, often worked where newer, faster readers which rely on an Internet Wi-Fi or 4G connection, would not.

Cash for cash-back had to be brought in daily from the nearest towns with working ATMs, using a large number of cards to get round the cards' daily limits. All completely legal, but security guards in local supermarkets with ATMs started to get very suspicious. So yes, the old adage, 'cash is king' still holds good. Always carry some.

Where to store money

Meanwhile, there is talk of a flight from gold as a standard currency, thanks to a global shift to cryptocurrency. Set aside the roller-coaster fortunes of all aspects of crypto, a City moneyman recently put an alternative real-world view:

'We are fortunate [in the UK] in having official government schemes [eg, the FSCS, Financial Services Compensation Scheme] that guarantee some compensation if a conventional bank fails. But in many countries, such as China, there are no comparably solid bank failure compensation schemes. And in all countries these compensation schemes generally do not cover crypto.

'If you live in China and want to be sure of your savings, where are you going to keep money?' the moneyman asked rhetorically, 'In a bank, or as crypto, or under the bed as gold bars?'

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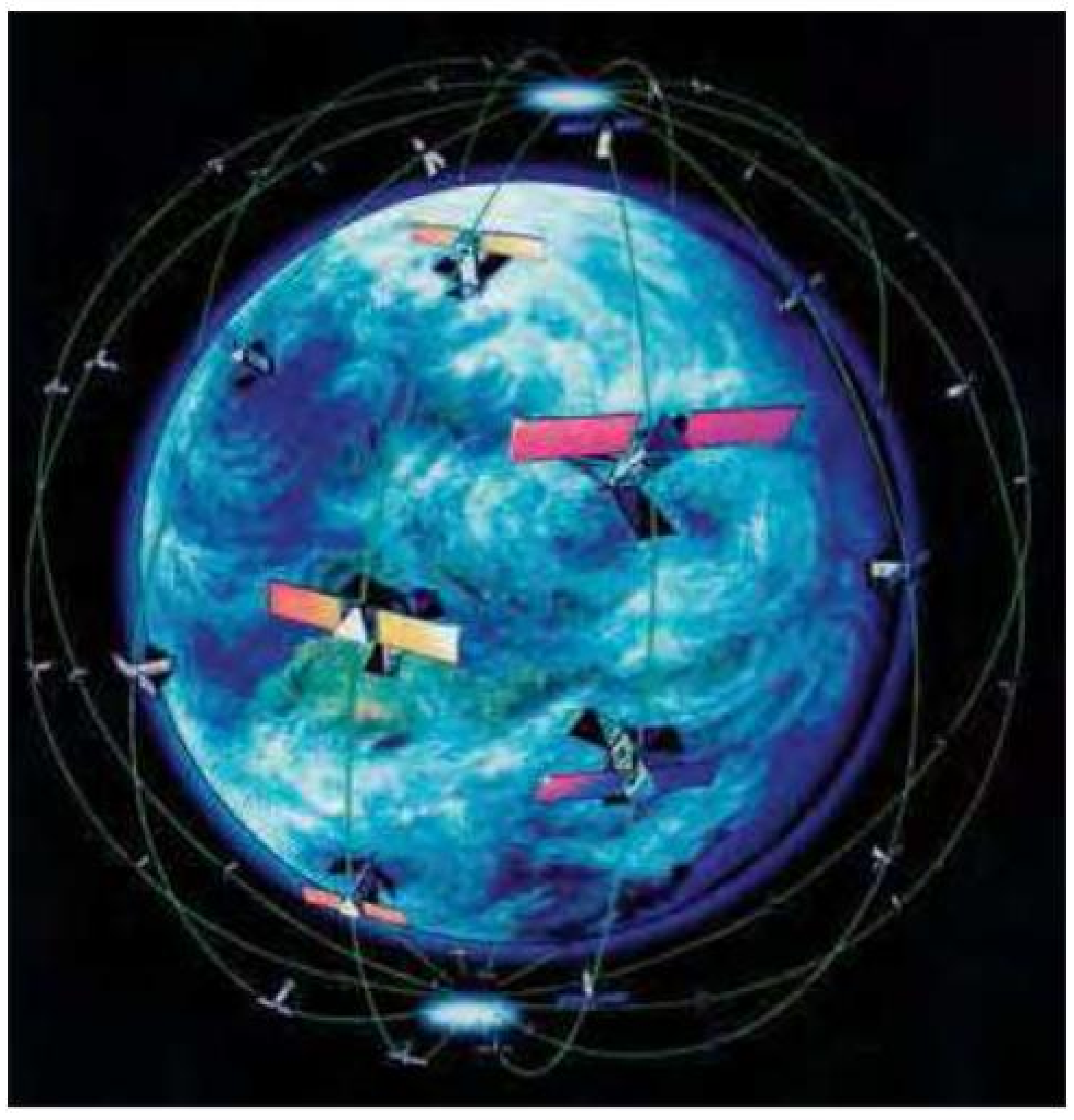
tekkiepix pic of the month – Iridium



Motorola laid plans for a satellite phone system way back in the early 1990s, when different countries were using different and incompatible analogue cell phone technology. In the US, cellphones registered in one state would not work in another. The idea of a global system with one handset working anywhere in the world, sounded wonderfully attractive.

Motorola's original scheme was to launch 77 satellites that circled the earth in a pattern of low orbits, and which were cleverly mapped to ensure that a handset on the ground could always 'see' at least one satellite overhead. So, the hand-set could receive and transmit even in cities and valleys where there is no line of sight to a satellite in *geostationary* orbit over the equator.

The name 'Iridium' was chosen as it's the 77th element. Later, Motorola decided to cut costs by launching only 66 satellites with half a dozen working spares, but decided not to change the name to 'dysprosium'.

Motorola built a factory in Arizona to mass produce the satellites and control them in orbit. After test transmissions, Iridium announced that it had, 'started its commercial phase on November 1st 1998'. Poster adverts promised international cover. In the UK, Iridium's European head office in Germany referred all enquiries to cell phone service provider Orange, but Orange told enquirers that there would not be a commercial launch until the last quarter of 1999. The handset would cost at least £2,000 and there were no call tariffs yet, but calls were expected to cost several pounds a minute.

The omens were not good. The first review samples had very limited battery life and provided erratic connection. The GSM digital cell phone standard was by then being used in many countries, and local operators had roaming agreements which let travellers use their phones abroad. Roaming was also becoming normal in the US.

Although Iridium phones could be used with a modem and PC to send data, the standard had been set ten years before when modems were slow. Iridium handled data at only 2.4 kilobits/second which is one-quarter the speed of a GSM cell phone, which itself seemed painfully slow compared to 56k PC modems which cost next to nothing.

Bob Tomalski, a technical editor for *What Cell Phone?* magazine, managed to borrow an Iridium cell phone to try in Europe. 'Speech quality is appalling', he reported. 'It sounds like talking underwater through bubbles. At 2.4kilobits, it would take all day and cost a fortune to send a picture. It's Stone Age technology trapped in Space.'

Iridium soon went bust and the network was sold for a knockdown price – it now serves people in places, like remote mountains, deserts or ice flows, who will pay a high price for any call at all.

More technology stories and images at: **https://tekkiepix.com/stories**

Practical Electronics is delighted to be able to help promote Barry Fox's project to preserve the visual history of pre-Internet electronics.

Visit **www.tekkiepix.com** for fascinating stories and a chance to support this unique online collection.

Net Work

Alan Winstanley

This month's column pays homage to the role of Queen Elizabeth II (1926 – 2022) and how she embraced some of the new technologies that came to the fore in Britain during her long reign. We take in some nuclear power history along the way.

This has been a tumultuous year for *Net Work* readers in the United Kingdom. Earlier in 2022 we celebrated our Queen's Platinum Jubilee marking 70 years of her reign, and then we had a record-breaking sweltering summer heatwave followed by a change of Prime Minister. Just a few days later, Britain and the world witnessed history in the making with the news of the passing of Queen Elizabeth II followed by the enthronement of King Charles III.

This month's *Net Work* column pays homage to the Queen and her penchant for progress and modernisation. To borrow from a certain German car maker's strapline, the late Queen was very much in favour of 'advancement through technology'. As a 14-year-old, Princess Elizabeth's first radio broadcast in wartime 1940 was a warming *Children's Hour* message of hope addressed to children around the world evacuated from London and other cities. The broadcast can still be heard on the official Royal YouTube channel at: **https://youtu.be/VJI9LPFQth4** with a full transcript at: **www.royal.uk/wartime-broadcast-1940**

The Queen was always keen to use the latest in communications, so 65 years ago she wrote to the BBC to say she felt the time was right to televise her annual Christmas message for the first time. The BBC agreed, and the resulting grainy monochrome footage of the Queen's 1957 Christmas broadcast can be viewed at: **https://youtu.be/mBRP-o6Q85s**

In the swinging Sixties, the Queen would televise her Christmas message in colour for the first time in 1967. It does not appear to be archived anywhere, although a transcript is available at: **www.royal.uk/christmas-broadcast-1967**

For her televised 2022 Jubilee festivities, the Queen embraced the latest CGI with an endearing TV sketch featuring Paddington Bear and marmalade sandwiches, which is now immortalised at: **https://youtu.be/7UfiCa244XE**

The same Royal channel on YouTube is updated regularly in a timely fashion and, for those readers who may be interested, the first address of King Charles III went online for a global audience at: **https://youtu.be/E_5REdx2Vtk**

Royal (e)Mail

The Internet arrived in 1970s Britain in the form of a connection with America's ARPANET, the packet-switching network that interconnected several high-end institutes and military establishments. The Queen sent her first email in March 1976 while visiting the UK's Royal Signals and Radar Establishment (RSRE). Photos of the event celebrated the release of CORAL66, the programming language that originated in the RSRE, and the Queen was pictured symbolically pressing the Send button on a terminal to dispatch the first official Royal email. (Britain's National Physical Laboratory (NPL) played a definitive role in developing packet switching and the Internet, something I hope to return to in a future column. Incidentally, it would be another 20 years before the Internet started to catch on with mainstream users, hence my article, *The Internet: What's in it for you?*, published in July 1996, and which which prompted the first ever *Net Work* column in the August 1996 edition.)

An official Facebook page managed by the Royal Family would follow (**www.facebook.com/TheBritishMonarchy**) and while visiting London's Science Museum in October 2014, the Queen sent her first tweet, which read: 'It is a pleasure to open the Information Age exhibition today at the @ScienceMuseum and I hope people will enjoy visiting. Elizabeth R.' In 2019, again at the Science Museum, the Queen posted on The Royal Family's new Instagram account for the first time. One of Queen Elizabeth's last public appearances on television would turn out to be her poignant message during the Coronavirus epidemic in April 2020. It evoked her wartime spirit, and she made reference to that first ever Christmas message in 1940, which can be bookmarked at: **https://youtu.be/2klmuggOElE**

The Queen goes nuclear

The year before her first Christmas message was broadcast, the Queen saw how Britain was aspiring to become self-sufficient in electricity when, on 17 October 1956, she officially opened the world's first full-scale nuclear power station at Calder Hall in Cumberland,

CORAL 66
ON ARPANET
CORAL 66 on the
ARPANET

The Queen sends the first Royal email when visiting RSRE. (Photo: Peter Kirstein)

The Queen inaugurates the supply of nuclear-generated electricity to Britain's National Grid at the world's first full-scale nuclear power station at Calder Hall in 1956. (Image: YouTube/ British Pathé) northern England. It was ostensibly the first nuclear power station to produce electricity for domestic consumption. The northern town of Workington, 15 miles away from Calder Hall, became the first town in the world to receive light, heat and power from nuclear energy, and four hours later, the first nuclear-powered electricity was reaching London, the BBC reported (see: **https://bbc.in/3qCQfdY**).

Again, YouTube is a rich source of archive footage: a triumphant British Pathé news report entitled, *The Atom joins the Grid* (**https://youtu.be/DVBG-k0R15gA**) showed the Queen throwing a switch at an inauguration ceremony to 'turn on' Calder Hall's nuclear connection to the Grid for the first time. It was a major international event, with thousands of spectators watching and delegates from nearly 40 countries – even scientists from Cold War rival the USSR were invited to attend. The 'Grid' in question was (and still is) the National Grid, the UK's power network designed to interconnect all forms of available generation and distribute it around the country, see: **www.nationalgrid.com**

The Calder Hall site operated for 47 years before closing in 2003, becoming the oldest Magnox power station in the world. There's more about Calder Hall on the UK's Institute of Civil Engineers (ICE) website at: **https://bit.ly/pe-nov22-chall**

20
kWh
15
5
10

The first few kilowatt-hours of nuclear-generated electricity clock up on a ceremonial meter at Calder Hall. (Image: YouTube / British Pathé)

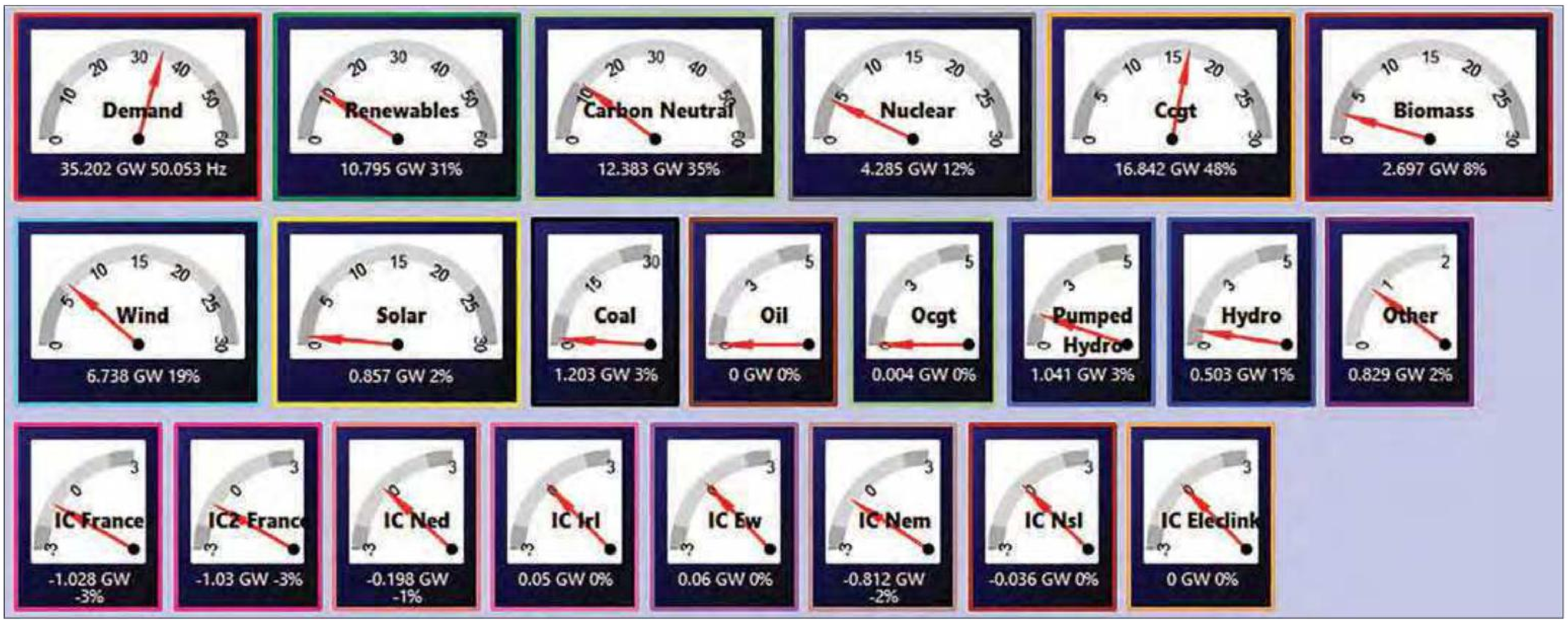
Too cheap to meter

Nuclear power promised boundless supplies of energy and would 'give us all the electricity we need, without the use of coal or oil', the Pathé voiceover trumpeted at the time. A contemporary American documentary about Calder Hall by **PeriscopeFilms.com** is also worth watching (see: **https://youtu.be/t8UJerSxlIo**). The film presenter reckoned that, as Britain was running out of coal for power stations, oil had to be imported and natural gas was 'non-existent', the country was pinning its hopes on nuclear energy instead: Britain was going to 'build fifteen new atomic power stations within the next ten years' and would be 'self-sufficient in power by 1975 or sooner', he said. As things turned out, UK coal extraction was already in decline and the Middle East oil crisis struck in 1973, but, thanks to the discovery of North Sea gas in the 1960s, by the early 1980s Britain had become a net exporter of oil, and by the mid 1990s an exporter of gas as well, according to Aberdeen University's Department of History.

Today, with global energy supplies in peril, the UK is racing to develop more nuclear, solar and wind power, while boosting gas exploration and fracking. The useful Gridwatch website (**gridwatch.co.uk**) gives a good approximation of current UK power consumption with bar charts and dials showing the split between different energy sources. At the time of writing, the country is using 35.2GW, of which 4.2GW is nuclear baseload and 5.7GW is wind. Interestingly, the interconnect (IC) dials show how power is either imported (+ve) or exported (–ve meter reading) using overseas sinks/sources such as those in France.

'Britain's own Chernobyl'

Historically, Britain's nuclear power programme nearly went into a literal meltdown when, a year after the ceremonial switch-on at Calder Hall, the country was shaken by an event that has been described as 'Britain's own Chernobyl'. In October 1957, at the neighbouring Windscale nuclear plant, some magnesium fuel cartridges jammed in a nuclear reactor pile, causing a huge temperature surge and risking a radiation leak into the environment. The resultant fire was barely kept under control, and it brought the nuclear plant to the brink of disaster. The fire took many days to extinguish,



The UK Gridwatch website is a very informative guide to energy consumption from all UK energy sources as well as foreign interconnects.

and this was only achieved by starving the 1,000°C inferno of oxygen as a last resort.

It seems that both the Calder Hall and Windscale plants were built primarily to fuel the H-bomb programme rather than for powering domestic homes. A report on the incident 65 years ago was suppressed by the Government to preserve Britain's supposed nuclear prowess in the eyes of her allies. A useful BBC exposé laid bare the Windscale incident, summarised at: **https://bbc.in/3DsWqJk** – there is plenty more on YouTube, including: **https://youtu.be/pxYz3lJ-iiQ**

The catastrophe seems to be long forgotten in the nation's psyche, no doubt due to Windscale being rebranded as Sellafield, a location commonly known for nuclear waste reprocessing and power generation. Its atomic weaponry roots are at least mentioned in the PR 'Welcome to Sellafield' at: **https://youtu.be/Fm2hpD8C4ks**

This major nuclear accident, followed by America's Three Mile Island fire in 1979 and Chernobyl in 1986, doubtless dented confidence in the nuclear power industry for decades. Britain has now re-vitalised its ambition to underpin the always-on 'baseload' supply with nuclear power; Sizewell B nuclear power station finally opened in 1995 but funding for Sizewell C has only recently been finalised and completion is at least a decade away. Many hopes are being pinned on new Small Modular Reactors (SMRs) taking up the slack, as described previously in *Net Work*, but they are also 8-10 years away, testimony to the country's early nuclear energy ambitions having faltered for half a century since the Queen first threw the switch at Calder Hall.

Looking forward to alternative energy

Still in a retrospective frame of mind, while sifting through our archives I found that *Everyday with Practical Electronics* had published a series on alternative energy exactly 30 years ago this month. A four-part series written in 1992 by popular *EPE* contributor Terry de Vaux Balbirnie described ambitions and developments using renewable energy sources, including plans for harnessing tidal power on the River Severn, Britain's longest river. The Severn tidal energy barrage sounded like an ideal candidate for generating 'green' energy, replacing up to five nuclear power stations, it was said. However, the idea was deemed unaffordable and was quietly dropped in 2010. It may re-emerge in the future if enough private investment can be raised.

Workers at the Windscale nuclear power station tackle the fire in 1957. The plant was subsequently rebranded as Sellafield. (Image: 'Windscale: The Story of Britain's Chernobyl' / Fascinating Horror / YouTube)

Other potential fuel sources described by Terry 30 years ago included hydrogen. Germany's BMW, a car maker that originally assembled Austin Sevens licensed from England, had been researching hydrogen as an automotive fuel since the 1980s, grappling with the non-trivial problem of avoiding cars exploding while storing liquid hydrogen at –253°C. BMW hoped to open the world's first hydrogen car test facility in 1989. (Good to know that one of BMW's ideas to prevent hydrogen build-up in the passenger compartment was to install sensors to automatically open the sliding sunroof, windows and boot/trunk to let the gas escape!) While hydrogen-powered cars could be a viable alternative to petrol, 'the quantity of [hydrogen] gas is not satisfactory to provide a sufficient range', Terry wrote. They had 'range anxiety' even then. The possibility of using fuel cells got just a one-line mention.

Wind power received a look-in too – one of the largest wind turbines in the world in 1992 was a 3MW 60m-diameter machine erected a few years earlier in 1987 on the Orkney Islands, off the Scottish coast. It powered 2,000 homes, but these large turbines were considered 'much too expensive for general use'. In the US, however, a 'wind farm' in California hosting 18,000 wind turbines generating 80kW each provided a total of 1.4MW. It had 'provided European researchers with much valuable information.' It was early days, but several European countries had already set targets for generating electricity using wind turbines. Denmark topped the list, having built 36-times more wind generating capacity (360MW) than the UK (10MW) by then.

Today, the UK is becoming a major manufacturer of wind turbines and now operates the world's largest offshore wind farm, Hornsea 2 in the North Sea. It can produce up to 1.32GW of electricity and became fully operational this year. The huge Dogger Bank offshore wind farm, midway between England and Denmark, will eclipse it and offer 3.6GW when it's completed. It will use the newest GE Haliade-X wind turbines which are three times larger than the earliest Orkney-based blades and can generate nearly five times more electricity, 14MW or more. The Haliade-X blades will be made in Britain (see *Net Work*, June 2021). More details can be found at: **https://doggerbank.com**

Smart solutions

The electricity generation sector is still learning to address the problem of balancing supply with demand, especially when wind conditions are sub-optimal. As readers know, the electricity and gas utilities are very keen to install smart meters in our homes, a topic well aired in previous columns (*Net Work*, December 2019 and January 2020). As a matter of course, I think smart meters will become instrumental in 'encouraging' consumers to reduce their demand at peak times when supplies are restricted. The National Grid must also maintain a safe operating margin or surplus 'headroom' to meet unexpected peaks in demand or outages in the network. The need to shape consumer demand is known as 'demand-side response' (DSR) and can be invoked in several ways: consumers can be bribed to switch off or use energy at off-peak times instead – eg, to charge an EV or use a washing machine overnight, by charging a lower price. Alternatively, they can be penalised by being charged more for peak-time consumption.

Much of the usage data for this is already available at a granular level, and I predict that it will only be a matter of time before imaginative new tariffs arrive that force users to pay more / use less depending on the 'spot' availability of renewable energy, seasonal weather conditions and time of day, with smart meters providing the necessary raw usage data. Digital In-Home Displays (IHDs) are also expected to start 'nagging' customers to switch things off, or customers might get a text message instead. Using a new Smart Meter Home Area Network (SMHAN), new appliances like washing machines, dishwashers or EV chargers will eventually be able communicate with them and will 'know' the optimum time to operate at the lowest cost, automatically.

Demand can also be reduced by switching to more energy-efficient appliances, as well as improving the insulation in our homes. This applies particularly to Britain's draughty, badly insulated post-war housing stock, built in the era of coal and gas-fired power stations when energy supplies were less of a problem. LED lighting is now universal too, and – credit where credit's due – it's sometimes hard to believe that a whole home can now be lit using the LED equivalent of a single 100W incandescent light bulb.

There is no doubt that smart meters can help many consumers to track and manage their energy consumption, and I know several people that swear by them (when they work properly). However, a number of energy-saving gadgets are also available to help consumers to monitor and control individual appliances. In next month's issue I'll review a typical Smart Wi-Fi mains socket that arrived on my desk recently and which has a number of useful power-saving features.

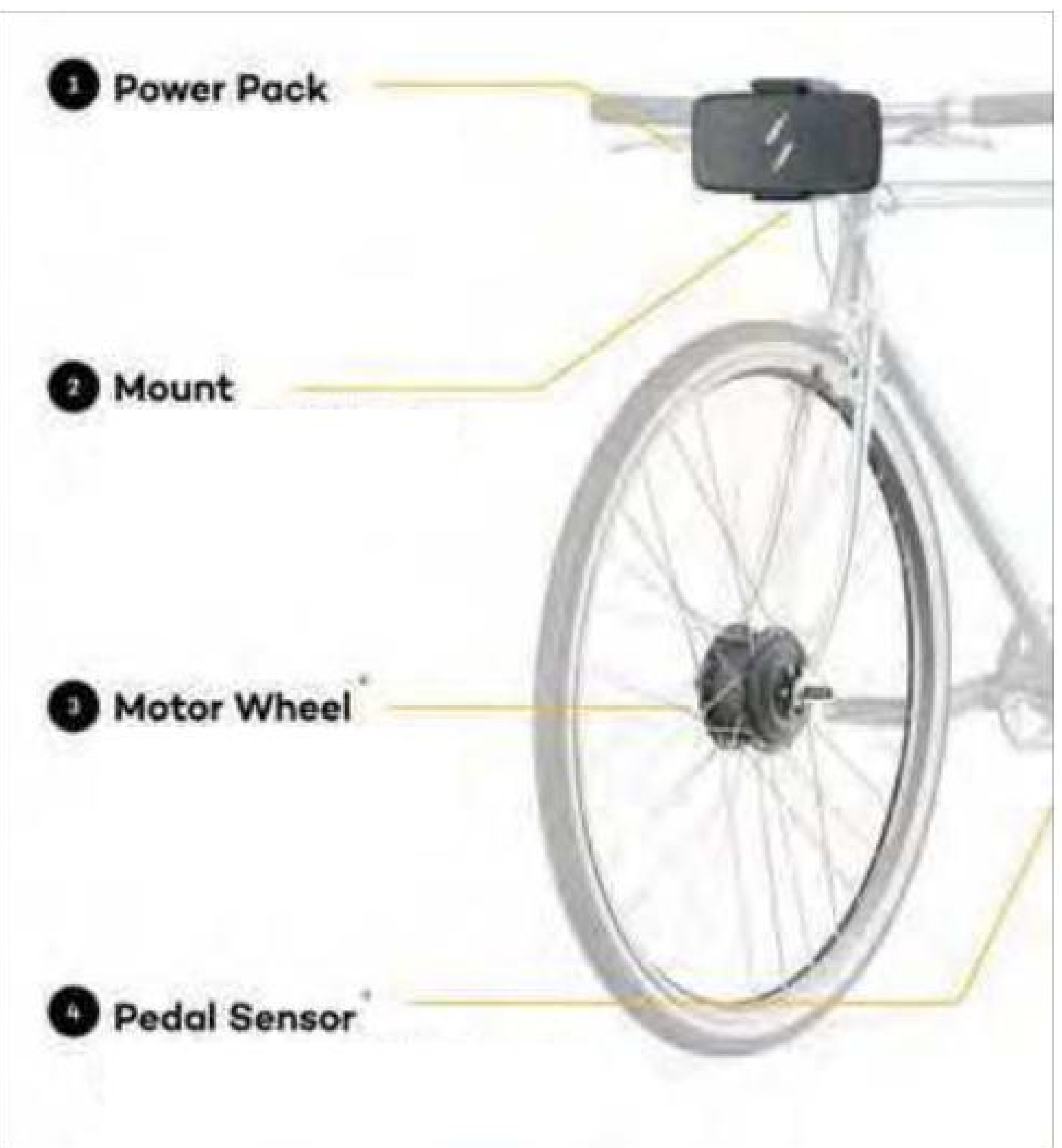
And finally

Last month, I suggested an entry-level whole-home wireless mesh system from Mercusys that was available at a rock-bottom price – a twin unit costs only £20. My trials saw four low-cost Mercusys Halo S12 AC1200 hubs dotted around the house, which were easy to install alongside my router's existing Wi-Fi (retained for a network printer) and a Devolo system that runs a smart TV and PVR, an IP camera and one of my favourite bits of network kit, a Synology NAS drive.

A couple of months later and the Mercusys system has been completely problem-free. In fact, I've been pleasantly surprised by the performance of this low-priced system, as it has a decent working range even when I'm outdoors. Despite its basic 1200 Mbps bandwidth, I had no issues streaming TV to a laptop some 40m away out in the garden or making WhatsApp video calls on a phone, though there might be the odd blip or freeze when, say, an email arrived. I could also stream radio via my smartphone and listen on a pair of Bluetooth earbuds. The Halo S12 has proved very workable so far, and it's a cheap, easy and effective way of adding whole-home mesh Wi-Fi to a home network. Higher-spec models are available, including a triple-pack Halo 50G AC1900 version (with gigabit Ethernet ports), costing about £75 when last checked on Amazon. This would offer greater flexibility for streaming 4K video, driving IP cameras and IoT devices, and seems like a good choice for more demanding users.

Britain's Competition and Markets Authority (CMA) has finally approved a £6bn merger between anti-virus software vendors NortonLifeLock Inc and Avast plc. NortonLifeLock was previously taken to court by the CMA over its refusal to cooperate with the CMA over their anti-virus auto-renewals policies. A no-fault undertaking was then agreed by Norton and 'transparency' has been improved.

As mentioned in previous *Net Work* columns, Volkswagen's forthcoming new Polo is launching with an optional 'Travel Assist' package, 'designed to make light work of long journeys.' It's based on a capacitive steering wheel which can detect if drivers physically have their hands on the wheel. (Perhaps, the car horn honks to wake you up?)



A new kit from Swytch converts almost any ordinary bicycle into an electrically assisted one. The removable 36V battery mounts on the handlebars and a brushless motor powers a custom-made wheel.

British start-up Swytch has just launched a new conversion kit that turns an ordinary bike into an electrically propelled one by replacing a wheel with a new high-tech motor wheel that is custom-built to the correct size that fits your bike. It has a 250W three phase brushless motor and a demountable 'Swytch kit' 36V battery that fits on the handlebars. It will fit almost any type of bicycle – more information is at: **www.swytchbike.com**

That's all for this month's *Net Work*. Remember that this article's web links will be ready-made for you to click on in the *Net Work* blog available at: **www.electronpublishing.com**

The author can be reached at:
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Part 1: by Tim Blythman

USB Cable Tester

It's frustrating when a USB device doesn't work, and you don't know if it's a problem with the device itself or the cable. This is a huge problem if, like us, you have a drawer full of USB cables and don't know which ones are good or provide power only. Bad cables can also cause intermittent problems. Now there is an easy way to test all manner of USB cables; this USB Cable Tester is so handy, we think you will find it indispensable!

Few things are as frustrating as an intermittent fault when it comes to checking and diagnosing faulty gear. It's even worse if it is due to a dodgy cable because you can never be completely confident that you have ruled out other problems. So for this reason it's crucial to be able to test cables.

These days, a lot of gear connects with USB cables and not just when it's attached to a computer. Practically all mobile phones use USB for charging, and they've also found many niche uses due to their ubiquity, even for devices like shavers and toothbrushes.

So we've designed a *USB Cable Tester* that can check practically all standard USB cables. If you're like us, you probably have a mix of the latest cables (such as USB-C) and a good number of older types (such as mini- and micro-USB).

The *USB Cable Tester* will test any cable with either a USB-C or USB-A (2.0 or 3.2) plug on one end and any USB-C or USB-B plugs (such as 2.0, 3.2, micro or mini) on the other end. With some basic adaptors, you can also test common variants such as OTG ('on-the-go') cables and non-standard cables, such as those with USB-A plugs at both ends.

This device is compact and automatic. Simply plug a cable into the appropriate sockets, and it immediately gives you an assessment. You will know straight away if the cable is suitable for your purpose.

Testing

The *USB Cable Tester* performs two primary tests. Initially, the various conductors in each cable are tested for continuity at low current.

This test can pick up whether, for example, a given lead has the appropriate internal data connections for USB 2.0 or USB 3.2, or whether it can carry power only. It can also detect internal short circuits which can interfere with normal operation.

The *USB Cable Tester* can also perform a high-current test on the VBUS and GND leads to establish how much current the cable can handle without dropping excessive voltage.

Checking the ability of the cable to carry current is arguably the most useful test, as it allows detection of the most subtle and intermittent faults. These are the faults where the device seems to operate normally but fails when a burst of current is needed. The device resets due to its supply dropping out and might even immediately start working again.

Devices such as portable hard drives, which often require significant current, are especially prone to this problem.

None of these tests characterise the high-speed data performance of the cable; much more specialised equipment is needed to do this. Still, these tests are performed very quickly and can be used to give a very fast 'go/no-go' assessment on a cable.

With the rise of the 'Right to Repair' movement, we think that the *USB Cable Tester* will become indispensable in places like Repair Cafés. We shudder to think how much good gear has been discarded due to having a faulty USB cable.

Power and USB 3

USB power delivery is a relatively recent addition to the USB standards and is not something our unit tests; these power delivery features are usually built into devices rather than cables.

Note that in this description of the *USB Cable Tester* we use 'USB 3.2' to refer to any cables that you might know as USB 3.0 or USB 3.1, since the USB 3.2 standard replaced (and is backwards compatible with) both USB 3.0 and USB 3.1. This is a similar situation to the way that USB 2.0 encompassed

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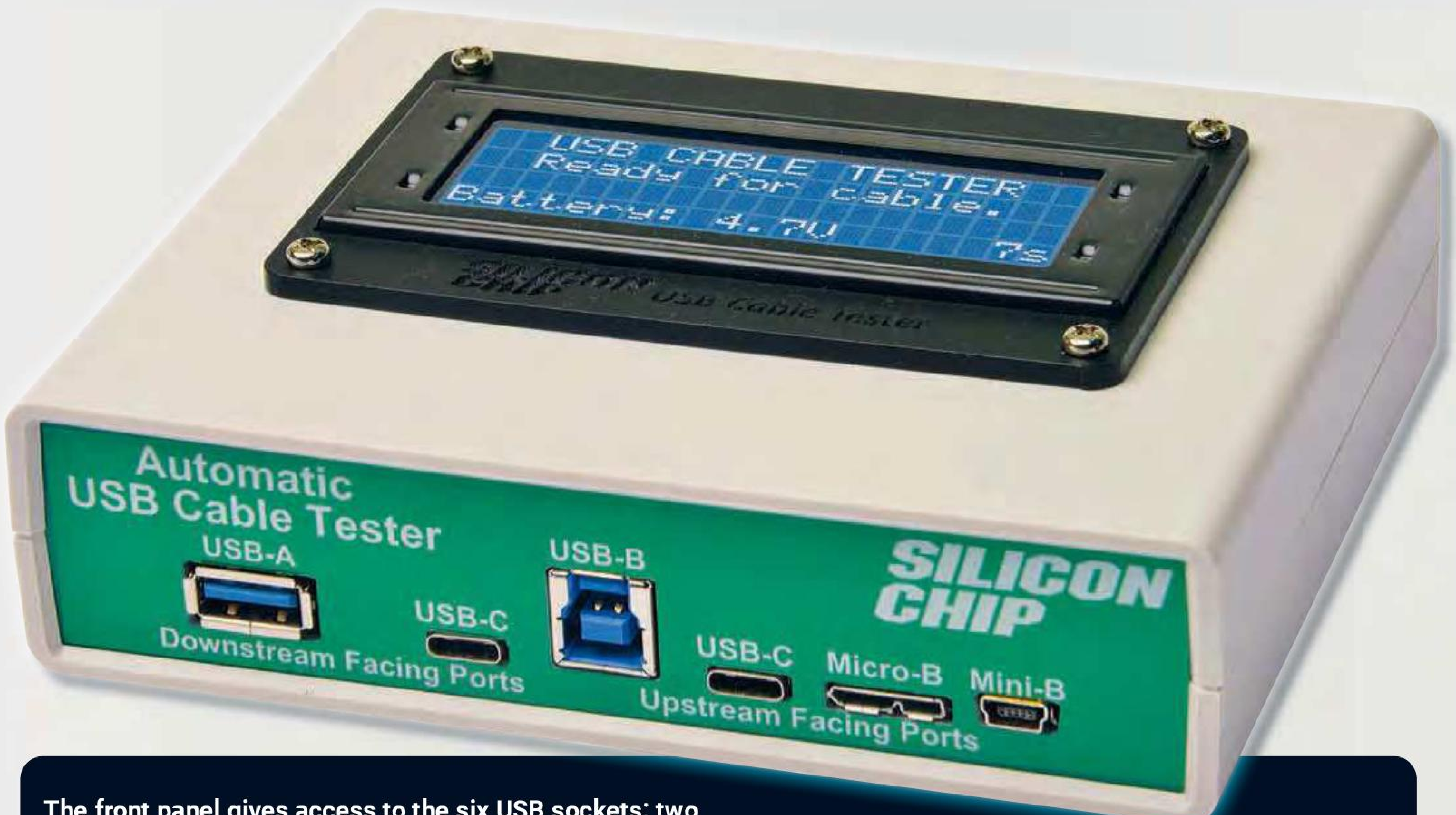


The front panel gives access to the six USB sockets: two downstream-facing ports (DFPs) at left and four upstream-facing ports (UFPs) at right. To test a cable, you plug one end into either of the DFPs and the other end into one of the UFPs. It does the rest automatically.

and replaced USB 1.0 and USB 1.1; it's now common to refer to devices compatible with these as 'USB 2.0'.

Design

Before delving too deeply into the circuit details, we'll mention some of the design considerations that we made along the way. We designed the *USB Cable Tester* to be economical to build, easy to use and robust enough for regular use.

While it certainly would be possible to do this job without a microcontroller, that would entail a complicated design.

Add in the fact that the nature of the test results are often more than a simple numeric result or basic binary go/no go, and a microcontroller is an inevitable part of the circuit.

With that in mind, we've used a 40-pin PIC microcontroller. Any fewer pins would require a multiplexer or switch, adding complexity and cost. Rather than fall back on one of the old-fashioned 40-pin micros like the PIC16F877, we've decided to get with the times and use its modern descendant, the PIC16F18877.

The microcontroller displays the test results on a 20x4 character LCD, allowing simple 'human-readable' assessments to be delivered. Thus the *USB Cable Tester* can be used by even those with no electronics experience.

The low-power features of this new microcontroller mean that a power switch is not needed and can be omitted. This may seem like a small saving, but it's one less part to consider during design and construction and shaves a little off the cost. The *USB Cable Tester* simply sleeps between uses, sipping a tiny 30µA from the battery.

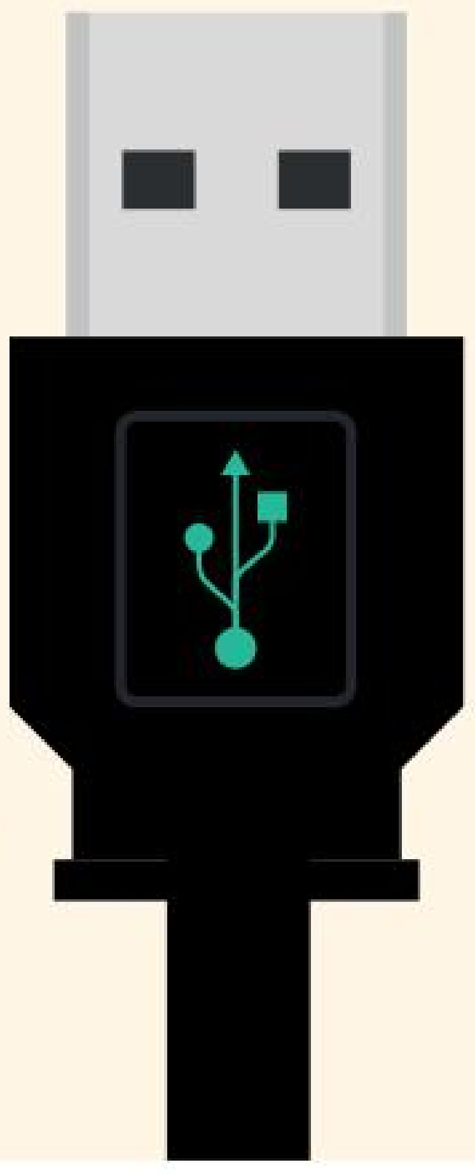
It runs from three AA cells which will last for many years with the *USB Cable Tester* sitting on the shelf. The 4.5V nominal supply voltage means that no regulator is needed; another part (and more money) saved.

The device is housed in a compact 140mm x 110mm x 35mm instrument case, about the smallest that would fit everything. This means that it is sturdy and looks the part, too.

Some parts we could not skimp on. The *USB Cable Tester* uses robust USB sockets, which cost a bit more but are paramount to the longevity of such a tool. We doubt that any other device will have USB leads plugged and unplugged so frequently.

Features and specifications for the USB Cable Tester

1. **Test just about any USB cable**
2. **Current pulse tests at 100mA, 500mA and 1A**
3. **Downstream-facing ports can accept USB-A (2.0/3.2) or USB-C (3.2)**
4. **Upstream-facing ports can accept USB-B (2.0/3.2), USB-C (3.2), Micro-B (2.0/3.2) or Mini-B (2.0)**
5. **Reports faults with individual cable ends (eg, plug with bare wires or detect OTG cables)**
6. **Can differentiate between power-only, USB 2.0 and USB 3.2 cables**
7. **Will report short circuits, open circuits and other faults**
8. **Reports voltage drop and cable resistance at usable currents**



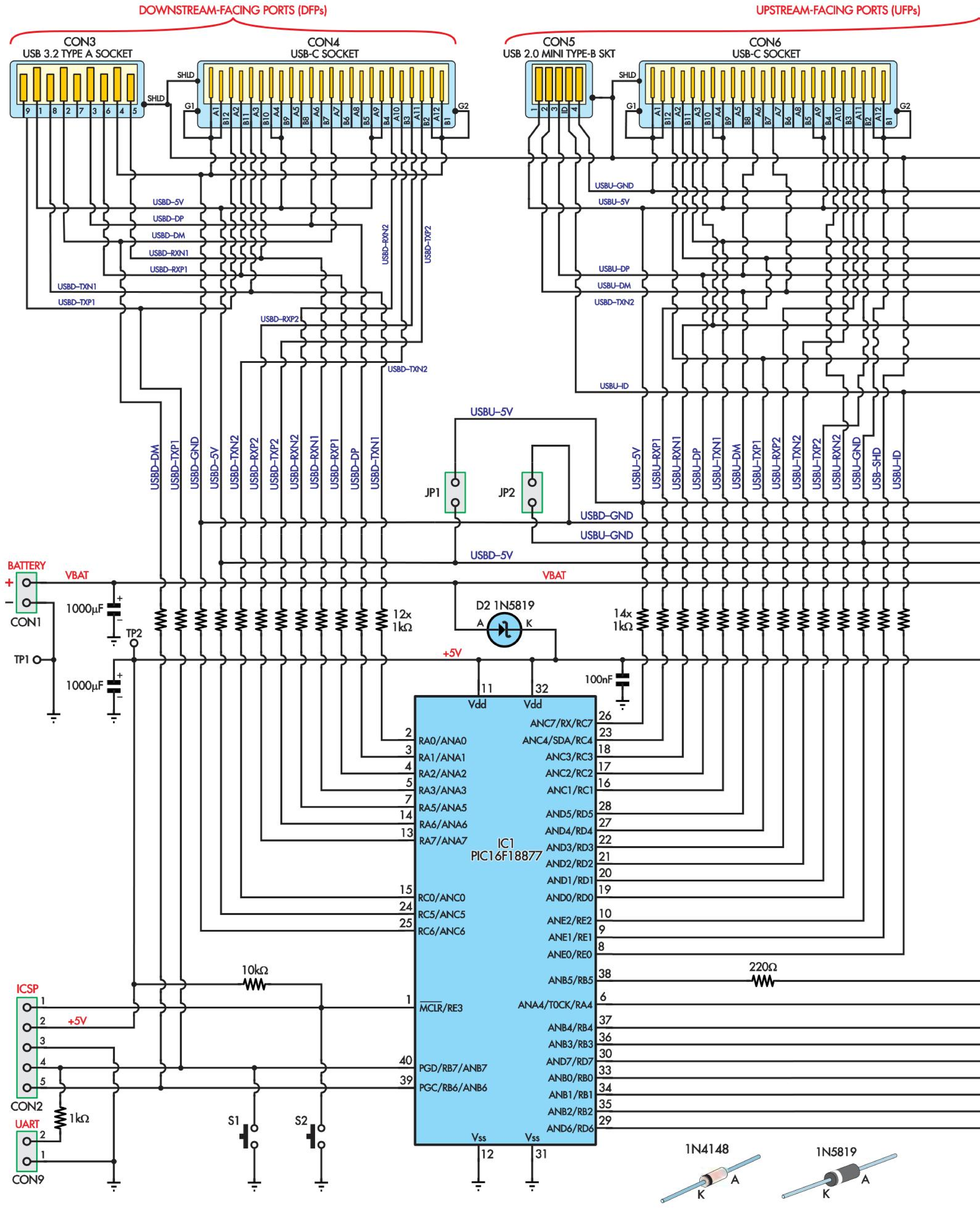
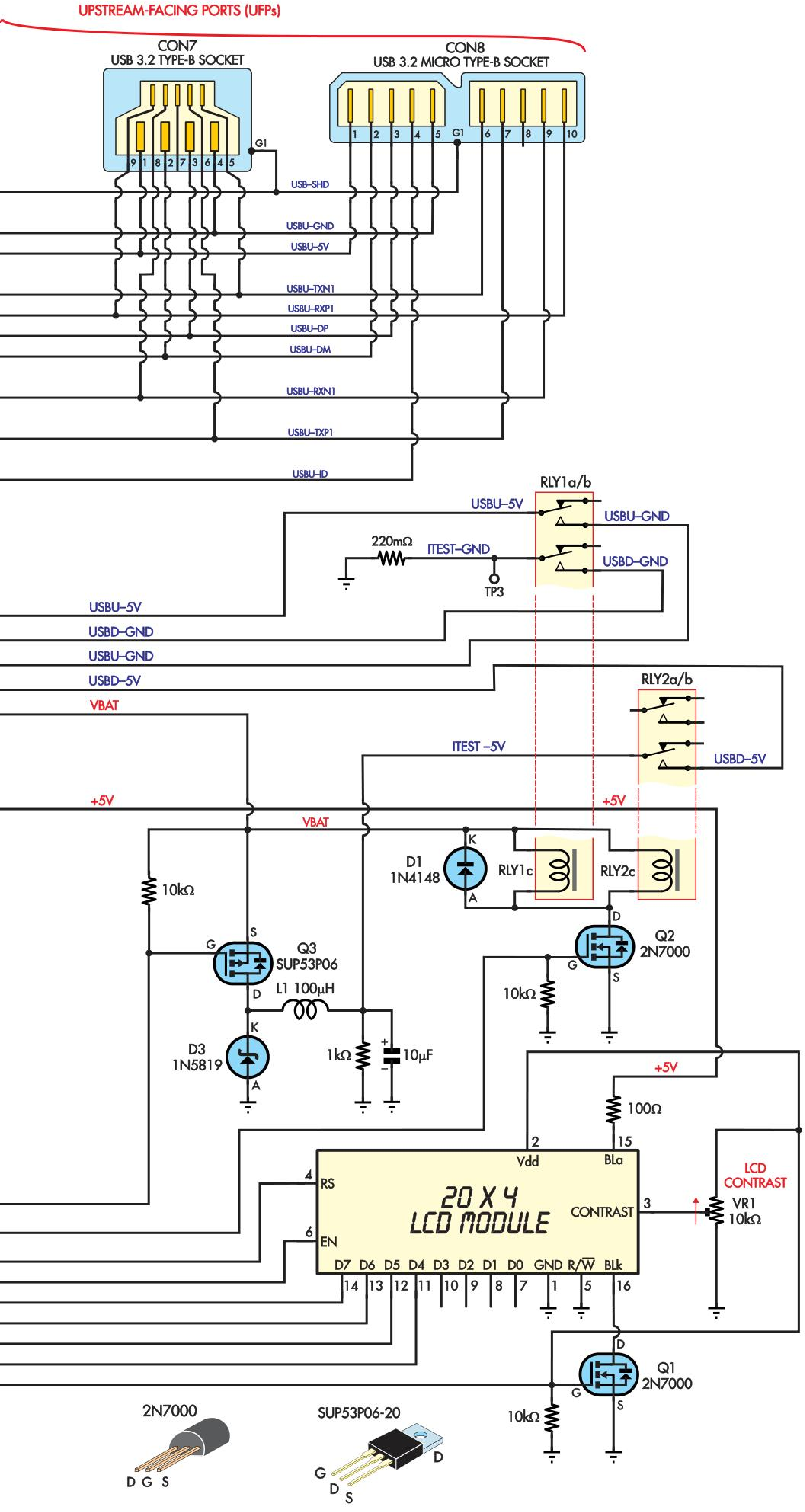

DOWNSTREAM-FACING PORTS (DFPs)
UPSTREAM-FACING PORTS (UFPs)
CON3
USB 3.2 TYPE A SOCKET
CON4
USB-C SOCKET
CON5
USB 2.0 MINI TYPE-B SKT
CON6
USB-C SOCKET
SHLD
G1
G2
A1 B12 A2 B11 A3 B10 A4 B9 A5 B8 A6 B7 A7 B6 A8 B5 A9 B4 A10 B3 A11 B2 A12 B1
9 1 8 2 7 3 6 4 5
1 2 3 ID 4
USBD–5V
USBD–DP
USBD–DM
USBD–RXN1
USBD–RXP1
USBD–TXN1
USBD–TXP1
USBD–RXP2
USBD–RXN2
USBD–TXP2
USBD–TXN2
USBU–GND
USBU–5V
USBU–DP
USBU–DM
USBU–TXN2
USBU–ID
USBU–5V
USBD–DM
USBD–TXP1
USBD–GND
USBD–5V
USBD–TXN2
USBD–RXP2
USBD–TXP2
USBD–RXN2
USBD–RXN1
USBD–RXP1
USBD–DP
USBD–TXN1
USBU–5V
USBU–RXP1
USBU–RXN1
USBU–DP
USBU–TXN1
USBU–DM
USBU–TXP1
USBU–RXP2
USBU–TXN2
USBU–TXP2
USBU–RXN2
USBU–GND
USB–SHD
USBU–ID
JP1
JP2
USBD–GND
USBU–GND
USBD–5V
BATTERY
+
–
VBAT
CON1
1000µF
TP1
TP2
1000µF
12x 1kΩ
D2 1N5819
A
K
+5V
14x 1kΩ
100nF
11
32
Vdd
Vdd
IC1
PIC16F18877
2 RA0/ANA0
3 RA1/ANA1
4 RA2/ANA2
5 RA3/ANA3
7 RA5/ANA5
14 RA6/ANA6
13 RA7/ANA7
15 RC0/ANC0
24 RC5/ANC5
25 RC6/ANC6
1 MCLR/RE3
40 PGD/RB7/ANB7
39 PGC/RB6/ANB6
26 ANC7/RX/RC7
23 ANC4/SDA/RC4
18 ANC3/RC3
17 ANC2/RC2
16 ANC1/RC1
28 AND5/RD5
27 AND4/RD4
22 AND3/RD3
21 AND2/RD2
20 AND1/RD1
19 AND0/RD0
10 ANE2/RE2
9 ANE1/RE1
8 ANE0/RE0
38 ANB5/RB5
6 ANA4/T0CK/RA4
37 ANB4/RB4
36 ANB3/RB3
30 AND7/RD7
33 ANB0/RB0
34 ANB1/RB1
35 ANB2/RB2
29 AND6/RD6
Vss
Vss
12
31
220Ω
10kΩ
ICSP
1
2
+5V
3
4
5
CON2
1kΩ
UART
2
1
CON9
S1
S2
1N4148
1N5819
K
A
K
A

Fig.1: like the PCB, much of the schematic is taken up by the 26 resistors that isolate the microcontroller from the USB sockets. In the unlikely event of a 'live' USB cable being plugged in, they will afford some protection to the microcontroller and whatever is at the other end.

We have chosen to use through-hole parts to allow the components to be easily obtained, and also so that the *USB Cable Tester* can be easily assembled. Nevertheless, this project does contain a handful of SMD parts for various reasons, primarily certain types of USB sockets. Many of these sockets are only available in that form.

Circuit details

Refer now to Fig.1 above, the complete circuit of the *USB Cable Tester*. CON3 and CON4 at upper left are the downstream-facing ports (DFPs)


UPSTREAM-FACING PORTS (UFPs)
CON7
USB 3.2 TYPE-B SOCKET
CON8
USB 3.2 MICRO TYPE-B SOCKET
G1
USBU-SHD
USBU-GND
USBU-5V
USBU-TXN1
USBU-RXP1
USBU-DP
USBU-DM
USBU-RXN1
USBU-TXP1
USBU-ID
RLY1a/b
USBU-5V
USBU-GND
220mΩ
ITEST-GND
USBD-GND
TP3
USBU-5V
USBD-GND
USBU-GND
USBD-5V
VBAT
RLY2a/b
ITEST -5V
USBD-5V
+5V
+5V
VBAT
D1
1N4148
RLY1c
RLY2c
10kΩ
Q3
SUP53P06
Q2
2N7000
L1 100µH
D3
1N5819
1kΩ
10µF
10kΩ
+5V
100Ω
20 X 4
LCD MODULE
Vdd
BLa
RS
EN
CONTRAST
LCD
CONTRAST
VR1
10kΩ
D7 D6 D5 D4 D3 D2 D1 D0 GND R/W BLk
Q1
2N7000
10kΩ
2N7000
D G S
SUP53P06-20
G
D
S
D

USB Cable Tester

– you can equate these to the 'host' ports from before USB-C. But since USB-C cables are end-to-end symmetrical, a new distinction needs to be made.

CON3 is a USB-A 3.2 capable socket, while CON4 is a USB-C socket (which by nature supports USB 3.2). CON3 will also accept older USB-A 2.0 cables since it is designed to be backwards compatible. CON5-CON8 are the upstream-facing ports (UFPs), analogous to the 'device' socket before USB 3.2. CON7 is USB-B 3.2 and, like CON3, can also accept a USB-B 2.0 plug; leads with these plugs are sometimes called 'printer leads' due to printers being one of the few items large enough to fit such a port.

CON6 is a USB-C socket and is accompanied by a USB micro-B socket, CON8. Like CON7, it can accept either a USB 2.0 or USB 3.2 plug. Finally, CON5 is a USB mini-B socket, which is only available in a USB 2.0 version.

The various pins from CON3-CON8 are connected to one of 26 1kΩ resistors. To reduce the number of pins that are needed, some pins are joined. For example, both the GND pins of CON3 and CON4 are connected to the same resistor.

That is because these pins perform similar functions in each connector and have no reason to be connected by a cable. They are functionally equivalent as far as the *USB Cable Tester* is concerned.

This means that the *USB Cable Tester* does not know whether the cable is plugged into the USB-A or USB-C socket, but that isn't necessary for checking cables.

As we noted earlier, a 40-pin microcontroller does much of the work. IC1 is a PIC16F18877 8-bit enhanced midrange microcontroller. It's one of the cheapest 40-pin microcontrollers available at the moment. There is a slightly more inexpensive version with less Flash memory, but given the ongoing chip shortages, we've decided to standardise on the part with more Flash.

26 of IC1's pins are connected to those 26 1kΩ resistors, and these pins are used to probe the connectivity of the cable which is being tested. Note that for the most part, IC1's GPIO (general purpose input/output) pins are interchangeable.

However, we use one feature that is not present on all the available pins, and that is the interrupt on change (IOC) feature. The ports that do have this feature have been wired into the downstream-facing ports.

Without using IOC, we would have to wake up the microcontroller periodically to test whether a cable is connected. This feature automatically wakes it up as soon as any connection is made between the downstream and upstream ports.

This made laying out the PCB slightly more complicated but allows IC1 to use the deepest sleep mode available, thus saving the most power when the unit is idle.

This circuitry is used to probe any pin combination between the upstream-facing port and the downstream-facing port. We'll explain how that works in more detail in the software section below.

Current affairs

The cable current-carrying capability is tested by sending a brief burst of power through the VBUS (5V) and GND wires of the cable under test. Since practically all the GPIO pins on IC1 can act as analogue inputs for its internal ADC (analogue-to-digital converter), we can probe the cable at several points to see how much voltage is dropped between them.

Up to 1A is supplied by a circuit based around Q3, a P-channel MOSFET. Q3, L1, D3 and the 10µF capacitor form a fairly standard buck (step-down) regulator arrangement.

When Q3 is switched on by a signal from the microcontroller via the 220Ω resistor, current flows from the battery positive through L1, charging the 10µF capacitor. When Q3 switches off, the inductor's magnetic field collapses, causing current to continue flowing to the capacitor, through the path provided via D3 and into the 10µF capacitor.

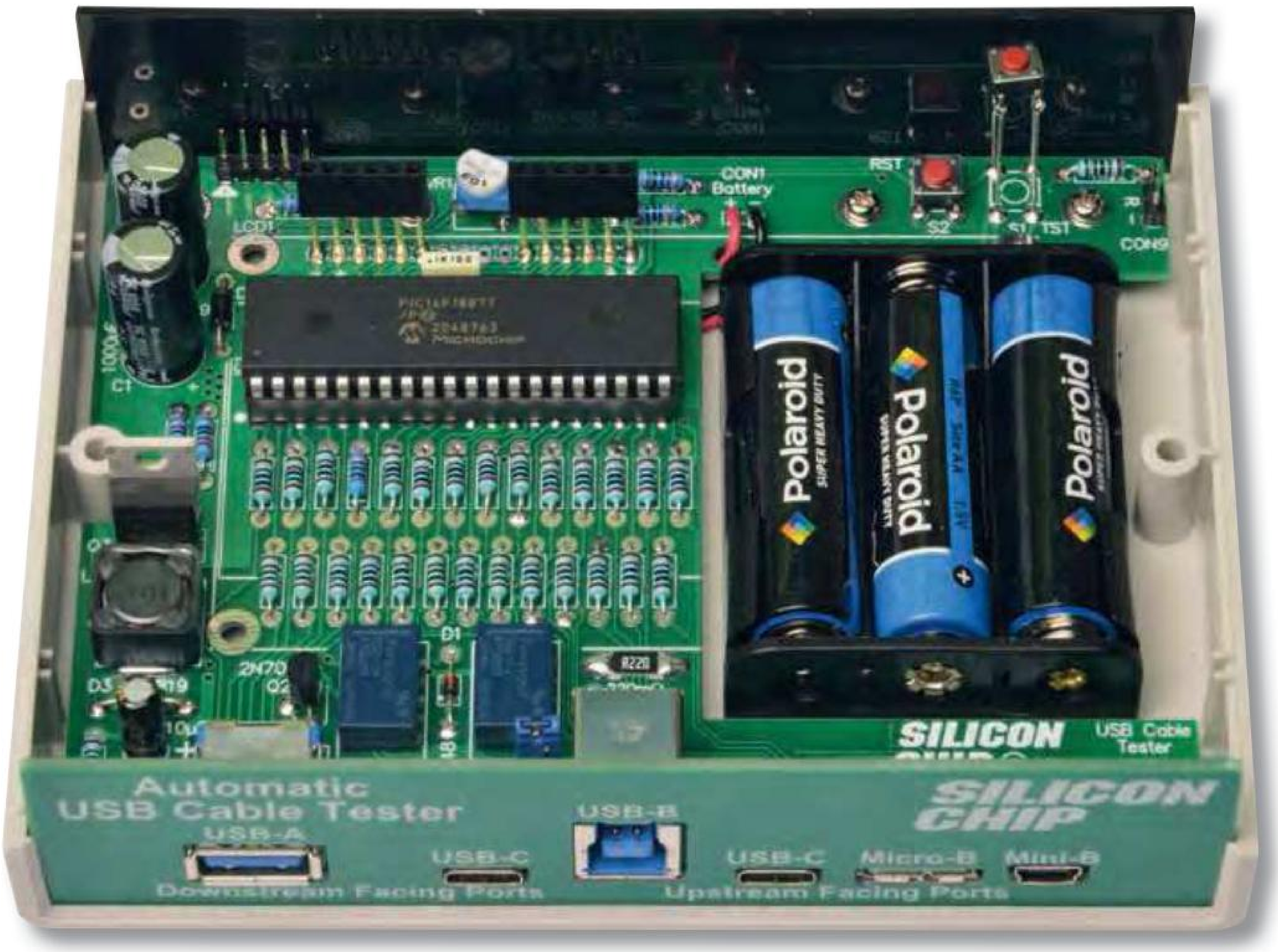
As in any other buck regulator, the duty cycle at Q3's gate determines the voltage that the capacitor charges up to but with the proviso that Q3 is a P-channel MOSFET and thus is on when its gate is pulled low. A 10kΩ resistor between Q3's gate and source keeps it turned off when it is not being driven.

The test voltage is applied to the cable by three of the contacts of RLY1 and RLY2. One set of contacts connects VBUS of the downstream-facing port to the positive end of the storage capacitor. The second set of contacts connects the GND of the downstream-facing port to the 220mΩ shunt resistor returned to circuit ground, used to measure the current.

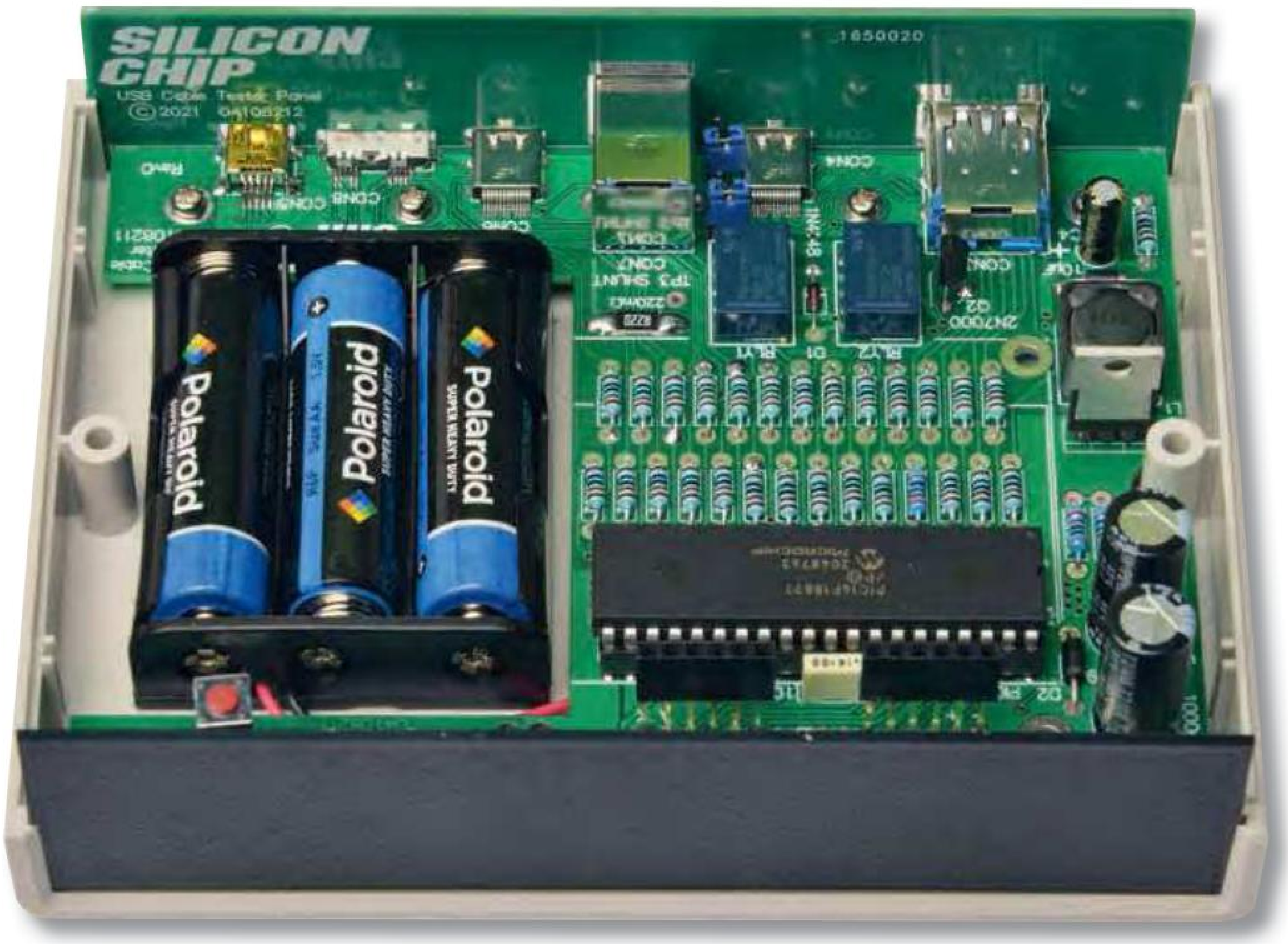
The third set of contacts connects VBUS and GND at the upstream-facing port, which is necessary to complete the circuit. Note that current flows in the same direction as it would under regular use.

It's important to realise that none of the USB GND connections are connected directly to the circuit ground during this test. They are connected to either end of the 220mΩ shunt resistor, but only when the relay contacts are closed.

The 1kΩ resistor across the 10µF capacitor discharges it when the buck regulator is not running. This is mainly to reduce the current flowing when the relay contacts open, reducing relay contact wear.



The completed USB Cable Tester photographed from the front and rear. This shows that all connections are made from the front of the case. One tactile switch is raised so it can be more easily accessed through a hole in the lid.



Both relays are controlled by N-channel MOSFET Q2, which sinks current from the battery through both relay coils when its gate is brought high by the microcontroller. A 10kΩ resistor keeps the MOSFET off when it is not being driven, and 1N4148 diode D1 absorbs the back-EMF from both coils.

As we noted, power is derived from three AA cells, giving a nominal 4.5V. A separate battery holder is wired into CON1. This feeds the 1000µF bulk bypassing capacitor, Q3 and powers the buck regulator and relay coils.

Schottky diode D2 feeds from the battery into microcontroller IC1's supply, bypassed by 1000µF and 100nF capacitors. These also provide power to the LCD. The diode means that the microcontroller's supply does not dip during the brief bursts of current draw during cable pulse testing.

Display

LCD1 is a 20x4 character LCD panel that has its supply fed directly from pin RD6 of IC1. The signal from RD6 is also connected to the gate of Q1, which switches the LCD panel backlight cathode via a 100Ω resistor. A 10kΩ resistor also holds Q1 off when the micro is not driving the pin.

Thus, when RD6 is low, LCD1 and its backlight are both off. When RD6 is taken high, LCD1's internal controller is activated and its backlight is switched on. This means that the *USB Cable Tester* can completely shut off power to the LCD when IC1 is in sleep mode.

Six more of IC1's pins are connected to LCD1 to control it in four-bit mode. This makes the best use of the available pins without needing a separate I/O expander chip.

CON2 is an optional in-circuit serial programming (ICSP) header for programming microcontroller IC1. The PGD and PGC pins are also used for USB cable sensing, so a USB cable must not be connected during programming.

The PGD pin is also connected to CON9, a two-pin header, via a 1kΩ resistor. CON9's other connection is circuit ground. This interface is used to connect to the transmit pin of a TTL-serial interface such as a USB-serial adaptor which can be used to enter a dedicated software interface for calibration.

No receive pin is provided. Instead, two-way communication is achieved by displaying data on the LCD screen during the calibration process.

Note that test points TP1, TP2 and TP3 are provided for calibration. These points connect to circuit ground, the positive microcontroller supply and the positive end of the 220mΩ shunt, respectively.

JP1 and JP2 are also used only for calibration. When bridged, JP1 connects the upstream and downstream-facing VBUS lines. Similarly, JP2 connects the upstream and downstream-facing GND lines.

When fitted, they leave only the relay contacts and shunt resistance in the current test circuit. Thus, the resistance of the relay contacts can be measured and entered into the calibration settings. This value is then subtracted from cable readings to give a true value.

S2 is also intended for calibration. It is connected to the microcontroller's reset line (which is usually pulled up by a 10kΩ resistor) and circuit ground. Since the calibration menu is only displayed just after a reset, pushing S2 is a simple way to reset the microcontroller and enter calibration mode.

S1 is connected between PGD and circuit ground. When it is pressed, it can trigger the IOC interrupt noted earlier and can thus be used to wake up the *USB Cable Tester* without plugging in a USB cable.

Software

The PIC16F18877 is a reasonably well-equipped microcontroller, and we're using several of its internal peripherals to provide the features needed.

Parts List – USB Cable Tester

1 double-sided PCB coded 04108211, 130mm x 102mm
1 double-sided PCB coded 04108212, 134mm x 30mm (front panel)
1 laser-cut acrylic bezel to suit LCD, coded SC5970 (optional)
Both PCBs and the bezel are available from the PE PCB Service
1 140mm x 110mm x 35mm plastic instrument case
[Jaycar HB5970, Altronics H0472]
1 3xAA battery holder with leads (CON1)
1 5-way pin header (CON2; **optional**, for ICSP)
1 USB-A 3.2 socket (CON3) **[Würth Elektronik 63.2213.200]**
2 USB-C sockets (CON4 and CON6) **[Würth Elektronik 632723.20011]**
1 Mini-USB socket (CON5)
1 USB-B 3.2 socket (CON7) **[Würth Elektronik 69222103.200]**
1 Micro-USB 3.2 socket (CON8) **[Würth Elektronik 69262203.200]**
1 2-way pin header (CON9; **optional**, for calibration ❶)
2 2-way pin headers and jumper shunts
(JP1 and JP2; **optional**, for calibration ❶)
1 20x4 LCD module (LCD1) **[eg, Jaycar QP5522]**
1 16-pin header, 2.54mm pitch (for LCD)
2 1A telecom relays, 5V DC coil (RLY1, RLY2) **[eg, EA2-5NU, Cat SC4158]**
2 6mm tactile switches (S1 and S2; **optional**, for calibration ❶)
1 100uH 12x12mm SMD inductor (L1) **[eg, Bourns SRR1280-101MCT]**
4 M3 x 15mm machine screws
8 M3 hex nuts
8 No.4 x 6mm self tapping screws or M3 x 6mm machine screws
2 6-way stackable headers (for mounting LCD)

Semiconductors
1 PIC16F18877-I/P ❷ microcontroller, flashed with 0410821A.HEX (IC1)
2 2N7000 N-channel MOSFETs, TO-92 (Q1, Q2)
1 SUP53P06 or IPP80P03P4 P-channel logic-level MOSFET, TO-220 (Q3)
1 1N4148 signal diode (D1)
2 1N5819 1A schottky diodes (D2, D3)

Capacitors
2 1000µF 6.3V electrolytic
1 10µF 16V electrolytic
1 100nF 63V MKT or 50V ceramic

Resistors *(all 1/4W axial 1% metal film except as noted)*
1 10kΩ mini horizontal trimpot
4 10kΩ 28 1kΩ 1 220Ω 1 100Ω
1 220mΩ 1% 2W M6432/2512 SMD

❶ *The USB Cable Tester will work fine without calibration, so these parts are optional. Still, see the text next month for information about how S1 can be used during regular operation.*

❷ *IC1 can also be a PIC16F18875 programmed with 0410821B.HEX. Either the I/P or E/P variants will work.*

The software loaded into the chip starts by initialising several of its internal peripherals. This includes setting most of the I/O pins as inputs with internal pull-ups, used to sense cable connectivity. It also sets up the UART (serial) receiver and PWM output for the buck converter, plus the seven I/O pins associated with the LCD.

Timer (T0) is configured to fire an interrupt every 262ms (approximately four times per second). This is a reasonable rate for quick screen updates while still allowing the display to be legible.

The timer is used to display a startup screen for around seven seconds. During this time, if an ESCAPE character is received on the UART, the calibration is started and a menu is displayed on the LCD. The calibration runs until either the microcontroller is reset or a Ctrl-C code is received on the UART.

Otherwise, the UART is disabled after seven seconds, and the main 'idle' screen is displayed. A subroutine is called after 10 seconds of the idle screen to put the *USB Cable Tester* into low-power sleep mode.

This involves shutting down the peripherals mentioned earlier and setting low all the pins associated with the LCD. This reduces the quiescent current as it avoids leakage from any floating input pins.

The upstream-facing ports are pulled to a low level, and the downstream-facing ports remain as inputs

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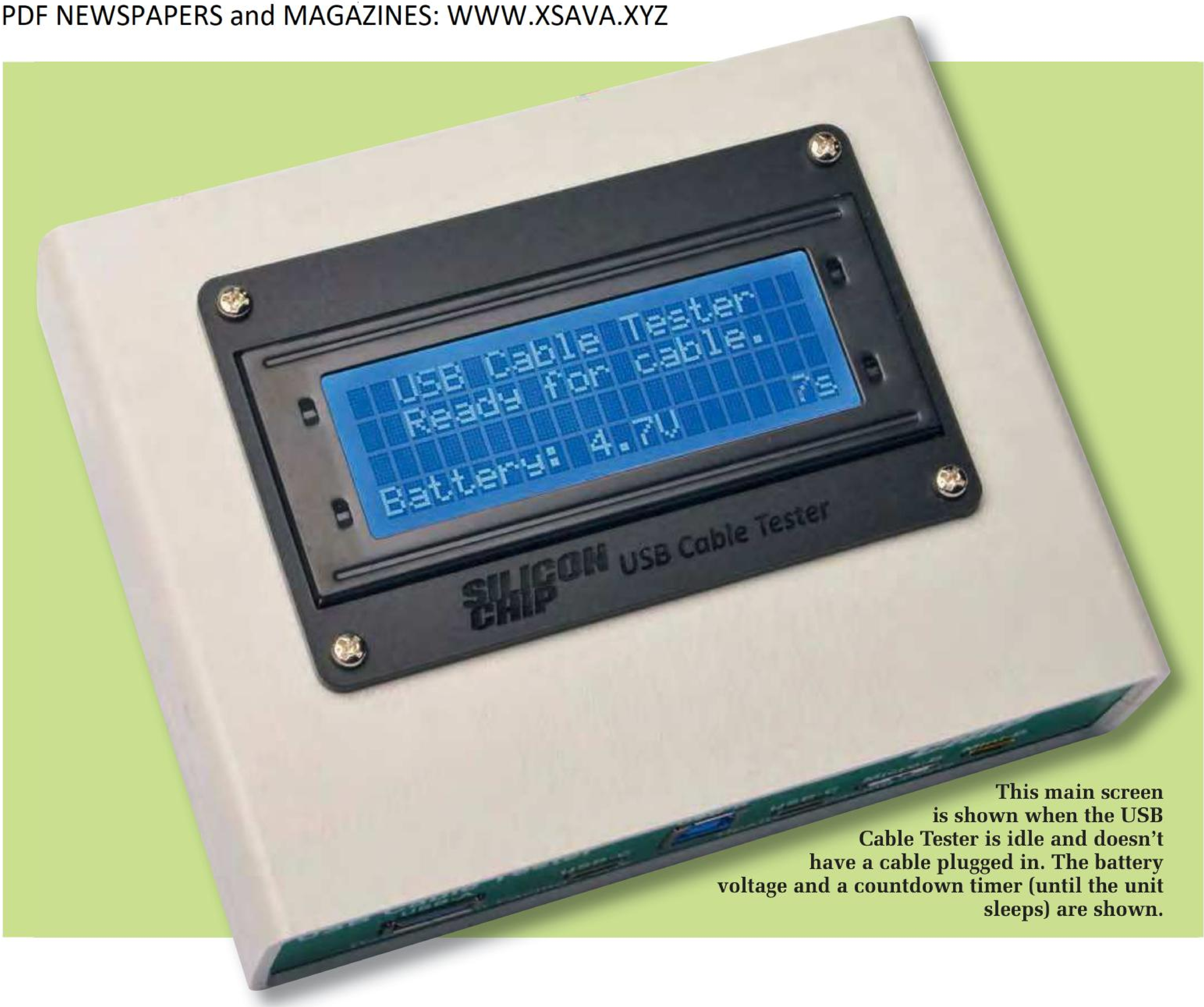


This main screen is shown when the USB Cable Tester is idle and doesn't have a cable plugged in. The battery voltage and a countdown timer (until the unit sleeps) are shown.

with pull-ups. Thus, any cable plugged in will pull one or more of the downstream-facing port pins low.

The IOC flags are set to allow a pin change to wake up the micro. Just before engaging sleep mode, the pins are checked one more time; if a cable is detected, sleep is bypassed. While unlikely to occur with so many pins, it is possible for a pin change to be missed, hence the reason for the double-check.

When a pin change is detected (which could include a press on S1), the micro wakes up and initialises all the peripherals again before returning to the main idle screen.

Whenever the micro is awake, it uses the timer to perform tests about four times per second. The results of the test dictate what is displayed. The idle screen is shown if no connection is detected; this also displays the battery voltage and a countdown timer until sleep occurs.

The tests work simply. Each pin is typically set as an input with a pull-up. One at a time – in turn – each pin is pulled low and the states of the other pins are tested. The wires in the USB cable connecting pins in downstream and upstream sockets result in other pins being detected as being low.

The tests are done in three phases. One phase simply checks for connections between the pins associated with the downstream-facing port. A second phase checks the upstream-facing port.

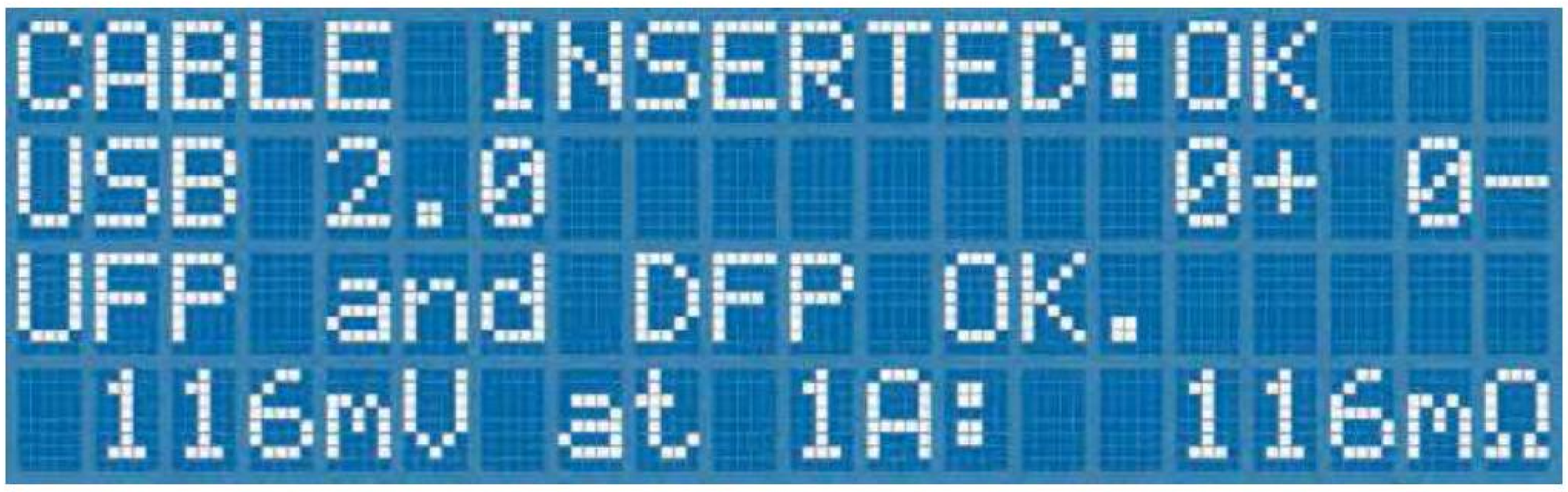
For the most part, these should show no connections, except perhaps for the cable shield and USB-ID pin. USB-ID is grounded on USB OTG cables to indicate that the equipment connected to what would normally be a 'device' needs to behave as a 'host'.

Depending on how the cable is wired, there might also be a connection between the cable shield and ground.

Any other connection within an upstream or downstream port likely indicates a cable fault. So if one end of a cable is plugged in, any of these sorts of problems that are detected are displayed on the LCD screen.

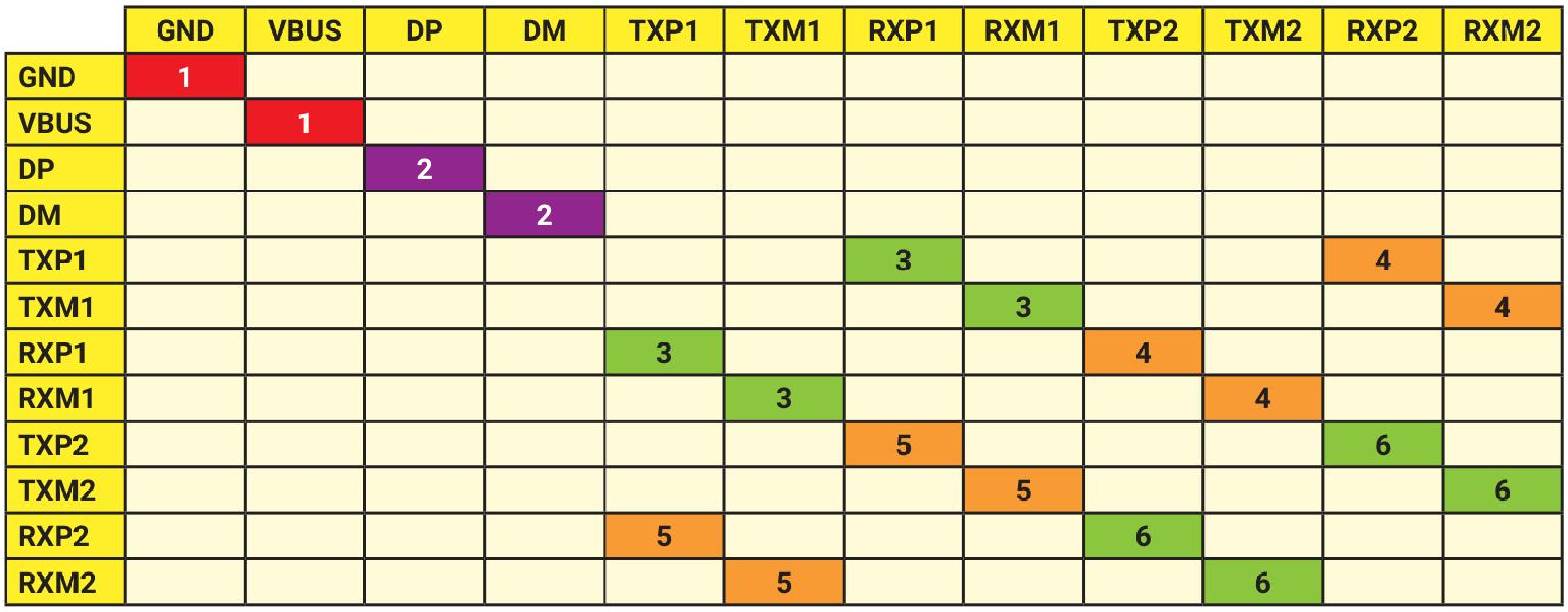
The third test phase is a complete 'matrix' analysis of every combination of downstream-facing port pin and upstream-facing port pin. This is turned into a cable-specific signature that is compared with a list of signatures corresponding to known cable types.

Some cable types have multiple signatures. For example, the reversible nature of USB-C means that there are two equally valid signatures for a USB



```
CABLE INSERTED:OK
USB 2.0        0+ 0-
UFP and DFP OK.
 116mV at 1A: 116mΩ
```

The Tester automatically runs tests as soon as a cable is plugged in. This known-good cable is identified as USB 2.0 compatible with no problems and a voltage drop of 116mV at 1A.



	GND	VBUS	DP	DM	TXP1	TXM1	RXP1	RXM1	TXP2	TXM2	RXP2	RXM2
GND	1											
VBUS		1										
DP			2									
DM				2								
TXP1							3				4	
TXM1								3				4
RXP1					3				4			
RXM1						3				4		
TXP2							5				6	
TXM2								5				6
RXP2					5				6			
RXM2						5				6		

Table 1: this data is stored in the microcontroller as arrays of 18 bytes, making up 144 bits (18 × 8). These correspond to the connection combinations that might be detected. It is compared with the data gathered during cable testing.

3.2 cable. Table 1 shows what connections are expected for each cable type.

An exact signature match means that the cable is a known type and displayed as such. An inexact match is shown as the nearest match and the differences are detected.

For example, the LCD might indicate that a USB 2.0 cable is detected, but with the D+ line open; such a cable may be suitable for a power-only application but will be no good for data transfer.

A simplified version of the decoding would work as follows.

- **Power-only cable:** just the red points in Table 1 detected.
- **USB 2.0 cable:** the red and mauve points are detected.
- **USB 3.2 cable (Gen 2x1):** as for USB 2.0, plus any one of the four remaining groups of connections.
- **USB 3.2 cable (Gen 2x2):** as for USB 2.0, plus either all the green points or all the orange points.

How we decided on which USB sockets to use

We have spent a great deal of effort to make sure that the sockets we are using for the *USB Cable Tester* are both durable and functional, as well as being hand-solderable. The latter is actually quite a tricky problem, especially for the USB-C parts.

USB-C packs a lot of pins into a small connector. Since there are two rows of pins in the connector, breaking them out into two rows at the PCB makes sense.

But having two rows of PCB pins will mean that the 'bottom' row cannot be surface-mounted, as there would be no way to access them from above. They'd be covered by the 'top' row of pins.

Since one row of pins goes through holes on the board, soldering them will be slightly easier. But we think these are the finest pitch through-hole and SMD parts that we have used in any project. You'll need to have the correct gear (including a magnifier and a syringe of flux paste).

Therefore, soldering these parts is the trickiest part of constructing the *USB Cable Tester*, despite our best efforts. Fortunately, the full-size USB-A and USB-B parts are simple through-hole devices.

We looked at utilising pre-built USB breakout boards, but they would have substantially increased the size of the final unit and cost quite a bit more too.

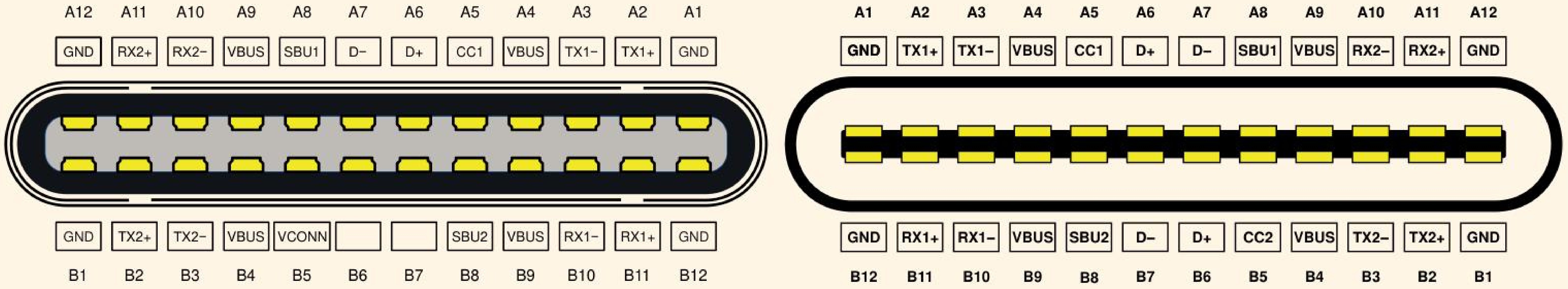
The mini-USB socket, CON5, is a part we've used many times before. Since there is no USB 3.2 variant of this connector, a standard USB 2.0 part is adequate.

The micro-USB part is small too, but not much different from the mini-USB socket. They both only have a single row of pins.

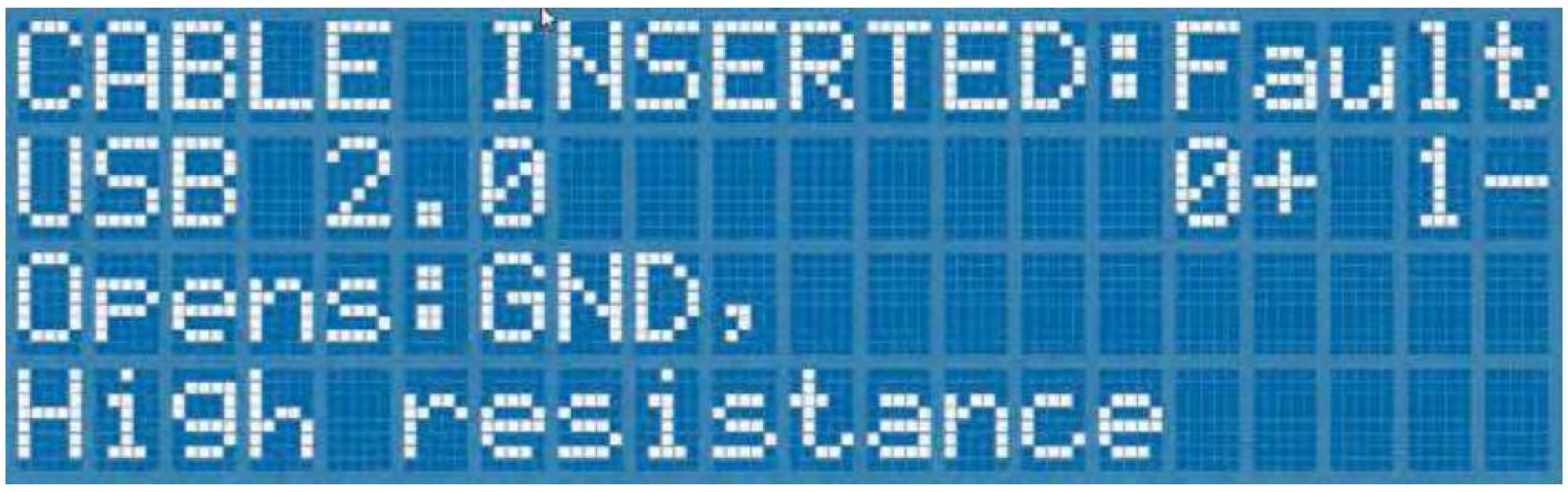
The good news is that you can use the circuit itself to test that the sockets are soldered correctly. We'll go into more detail during the construction, but briefly, we can use the existing hardware and logic to probe for any shorts in the socket soldering.

A short in the socket soldering will appear to the *USB Cable Tester* like a fault in the cable, even if it only occurs at one end. Thus, we will advise an unusual order of construction, so that the *USB Cable Tester's* microcontroller can run its tests during construction, well before it is complete.

That way, you can take your time and check your work both visually and electrically to ensure that you end up with a functioning *USB Cable Tester*.


A12 A11 A10 A9 A8 A7 A6 A5 A4 A3 A2 A1
GND RX2+ RX2– VBUS SBU1 D– D+ CC1 VBUS TX1– TX1+ GND
GND TX2+ TX2– VBUS VCONN SBU2 VBUS RX1– RX1+ GND
B1 B2 B3 B4 B5 B6 B7 B8 B9 B10 B11 B12
A1 A2 A3 A4 A5 A6 A7 A8 A9 A10 A11 A12
GND TX1+ TX1– VBUS CC1 D+ D– SBU1 VBUS RX2– RX2+ GND
GND RX1+ RX1– VBUS SBU2 D– D+ CC2 VBUS TX2– TX2+ GND
B12 B11 B10 B9 B8 B7 B6 B5 B4 B3 B2 B1

The two rows of closely spaced pins used in USB-C type plugs and sockets demand a tight pin pattern on the PCB. The part we have chosen will be the most challenging part of this project to solder, and we doubt there is anything easier to hand-solder available.



```
CABLE INSERTED:Fault
USB 2.0        0+ 1-
Opens:GND,
High resistance
```

A faulty cable is quickly identified; in this case, the GND wire is detected as open circuit (1-, Opens:GND) and naturally, it has no useful current-carrying capacity on its power lines.

Any additional connections detected beyond these constitute some form of short-circuit fault.

When a cable is detected, the current pulse test is also performed once every five seconds. This is only done periodically to reduce battery drain and relay wear. The first test is done about half a second after detection, to allow time for the cable to be fully inserted.

For this test, the micro sets all the pins associated with connectivity testing as inputs and closes the relays to complete the power circuit. The reference for the ADC is set to the 1.024V FVR (fixed voltage reference). Being a 10-bit ADC, each digital step then corresponds neatly to 1mV.

The micro ramps up the PWM signal to Q3 while monitoring the voltages at various points along the VBUS and GND wires of the cables, including just above the current measuring shunt, which allows the test current to be determined.

The ADC is sampled 16 times at four points over several PWM cycles to compensate for the relatively high amount of ripple in the applied voltage.

At 100mA, 500mA and 1A, the voltages are stored. If the measured voltage rises above 1V (at any point in the cable) at any time, the test is cut short. The 1.024V reference used for these measurements puts an upper limit on what can be meaningfully measured.

Another reason for cutting the test short is that it avoids a high load on the batteries. With a fixed 1A output, there is actually a greater load on the batteries when a high resistance cable is tested; this part of the circuit behaves much like a current source. In any case, a cable dropping anywhere near 1V is not going to be of much use.

The *USB Cable Tester* then displays the results from the highest test reading, including voltage drop and calculated cable resistance.

When the cable is unplugged, the *USB Cable Tester* returns to the idle screen and counts down its timer to enter sleep mode unless another cable is plugged in for testing.

Next month

Next month, we'll describe the construction, calibration and use of the *USB Cable Tester*.

We'll also describe how the *USB Cable Tester* can check its own construction and assist with finding soldering faults in the SMD USB sockets we are using. See the panel for more information about the sockets and why such a feature will be handy.

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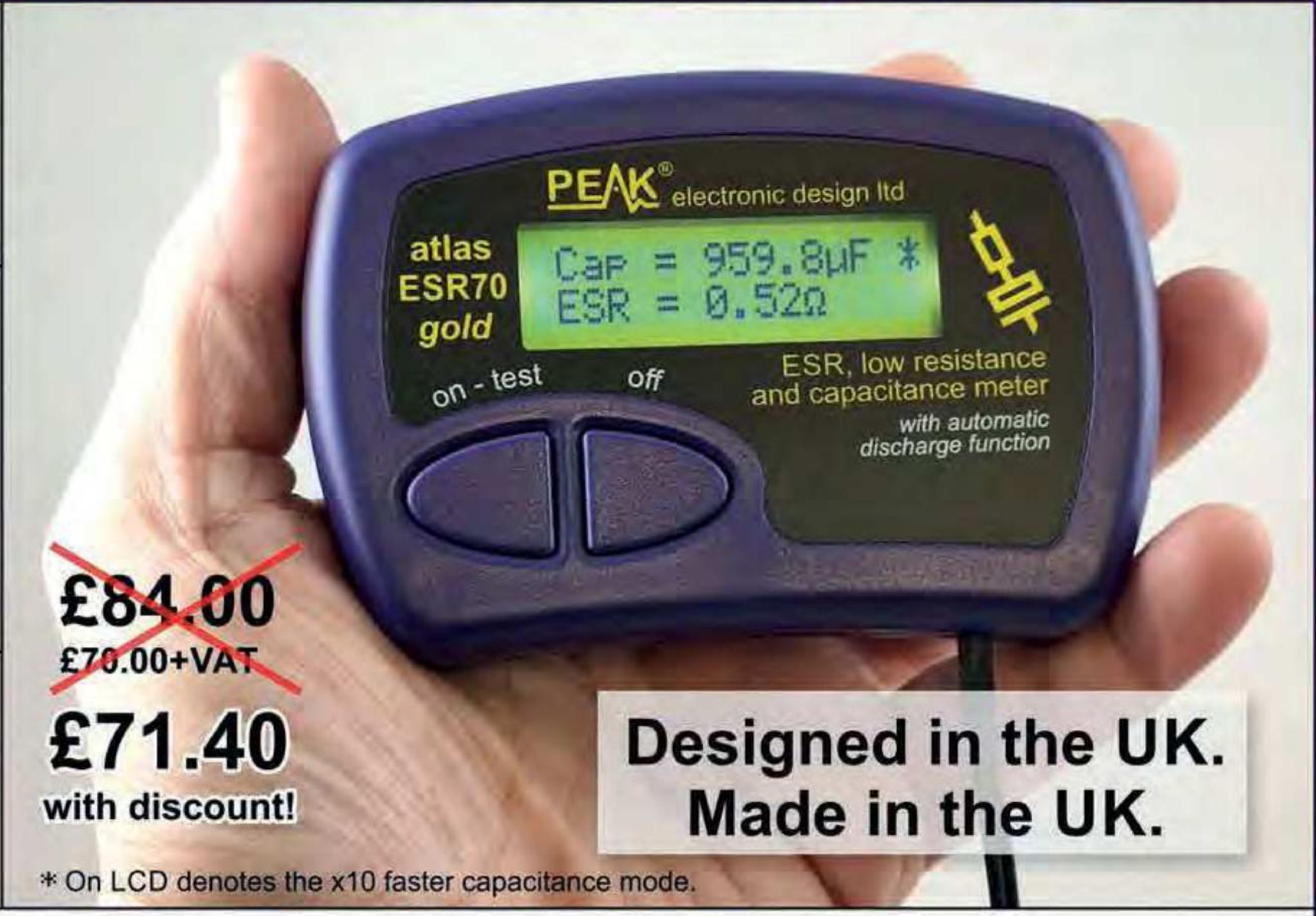

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POCKET WEATHER STATION

By Aarav Garg

We're often describing how you can buy and use very low-cost electronic modules. They're great because they save you a lot of assembly time and soldering work, and they often cost less than buying the individual parts you would need to build them. Here is an excellent beginners' project that uses five such modules to make something useful – a mini weather station you can carry everywhere with you.

Is it hot in here, or just me? That's a question you don't have to ask anymore with this *Pocket Weather Station*.

It is a compact device, powered by an Arduino Nano board that you can carry anywhere, right in your pocket. It displays the current temperature and humidity on its OLED screen. Sure, you may have the local weather report on your phone, but it's amazing how much local temperatures can vary from those recorded elsewhere in your area.

Plus, knowing the indoor temperature and humidity can be pretty helpful, as how hot or cold it 'feels' is strongly affected by humidity, not just temperature. Even with moderate temperatures, high humidity can make you sweat more than a more intense dry heat!

One reason it's so portable is beacuse of its integrated, rechargeable 160mAh LiPo battery.

It is an excellent project for learning and is also really fun to make. It even comes in handy sometimes! Sound interesting? Then let's dive right in!

First steps

The first thing to do when beginning with any project is gathering the required components. The required devices and modules are listed in the *Parts List*. They are mostly available from online marketplaces like eBay, AliExpress and Amazon.

While they are inexpensive, chances are they will come from overseas, so allow a few weeks (or even months) for delivery.

By the way, the DHT11 is a smaller, less accurate version of the DHT22 temperature/humidity sensor that we have used in the past and described in the April 2018 issue of *PE*. Its small size is useful in a pocket device.

Since it incorporates both temperature and humidity readings, we only need the one sensor. The other parts are the Arduino board to query it, the display to show the readings and the charger to keep the battery topped up.

You need a few basic tools to build the *Pocket Weather Station*: a soldering iron, hot glue gun (or even better, a tube of neutral-cure silicone sealant and a caulking gun) and, if you're going to make the optional case, access to a 3D printer.

Preparation

Now we need to plan the position of all the components inside the enclosure. I wanted to keep the device as thin as possible, so it is actually convenient to carry in a pocket. Thus, I spread all the components out and did not go with a layered structure. That would decrease the width and height, but increase the thickness.

Fig.1 shows how I stacked the components inside my *Pocket Weather Station*. I used an Arduino Nano board because of its size, which is perfect for this project. You could also come up with your own method of stacking the components in ways that reduce the size of the device even further.

After you have planned your preferred arrangement, refer to Fig.2, the wiring diagram. This shows how all the modules need to be connected. It's

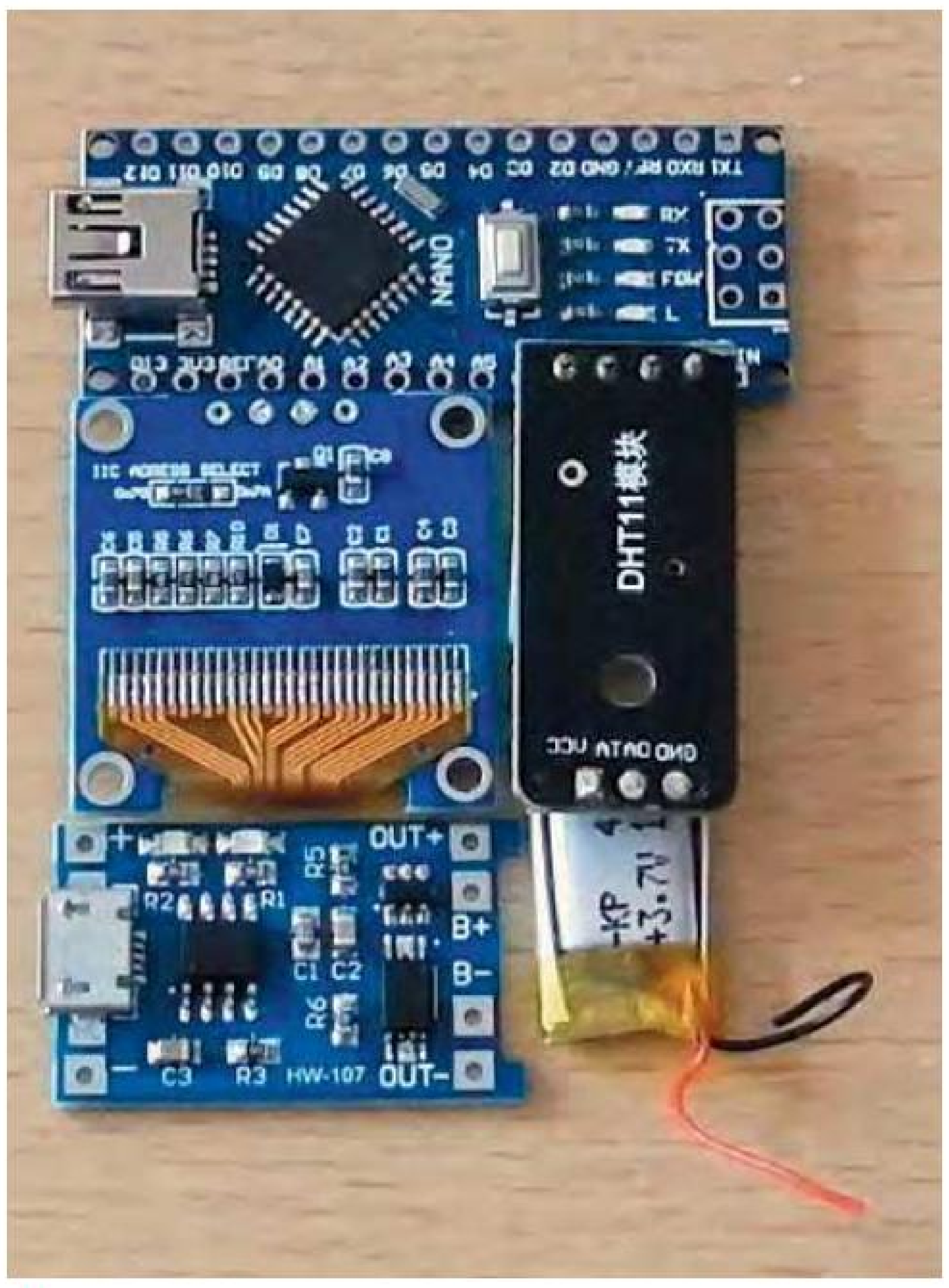


Fig.1: this is how I laid out the components so that they would fit inside a custom-made case.

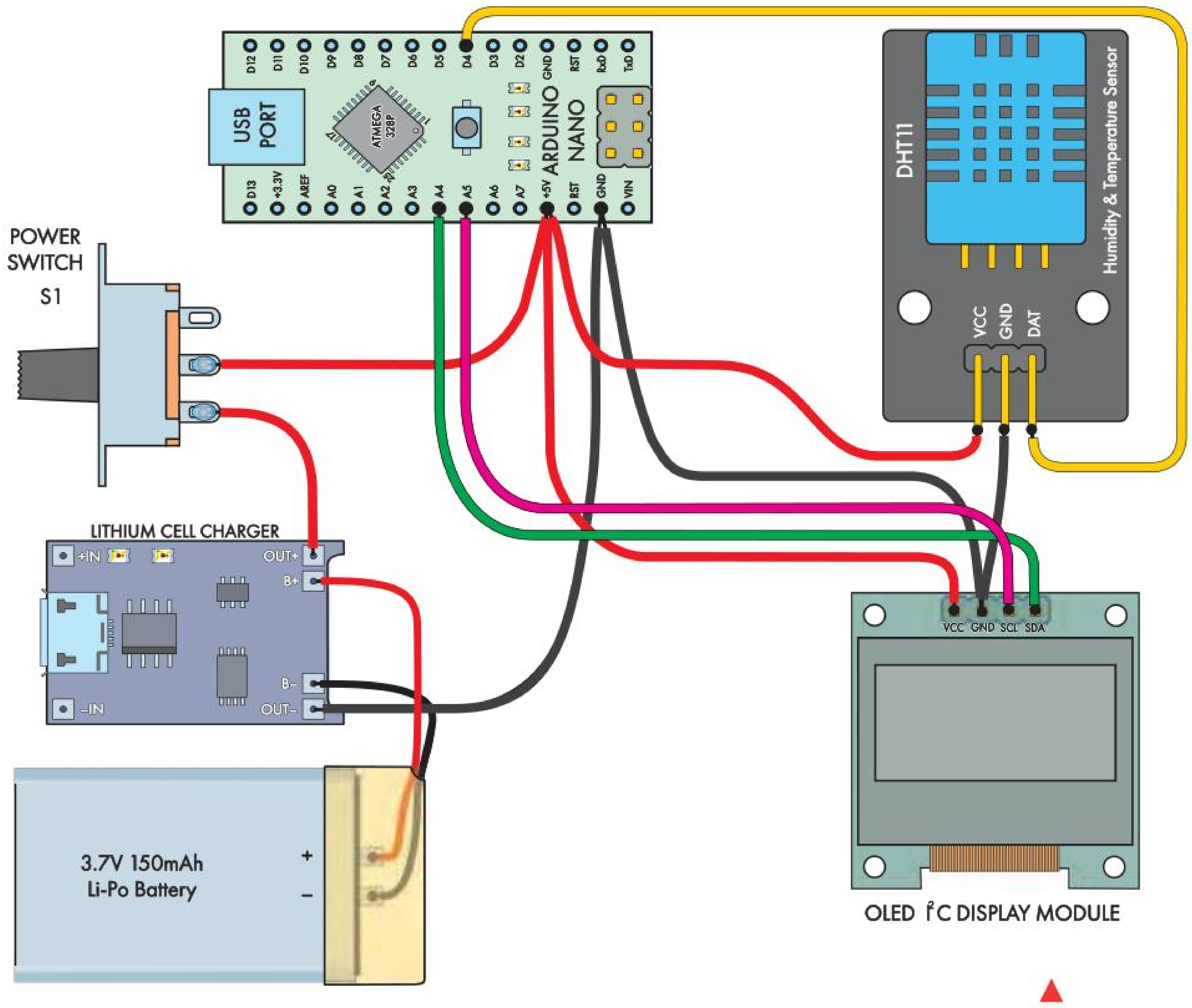

USB PORT
D12 D11 D10 D9 D8 D7 D6 D5 D4 D3 D2 GND RST RxD TxD
D13 +3.3V AREF A0 A1 A2 A3 A4 A5 A6 A7 +5V RST GND VIN
ATMEGA 328P
ARDUINO NANO
DHT11
Humidity & Temperature Sensor
VCC GND DAT
POWER SWITCH S1
LITHIUM CELL CHARGER
+IN
OUT+
B+
B-
OUT-
-IN
3.7V 150mAh Li-Po Battery
+
–
VCC GND SCL SDA
OLED I²C DISPLAY MODULE

Fig.2: this diagram serves as both the wiring diagram and a form of circuit diagram; it shows all the connections necessary to turn the separate modules into a Weather Station. You don't need to use the same colour coding as we did, but we strongly advise that you stick to the red/black colours for the power wires, and make sure that black only goes to ground or negative pads, and red to positive pads. Take note that different DHT11 modules may have different pin-outs.

relatively simple, as there are just a few modules, and none of them need to be modified.

Wiring it up

Before you start building the *Pocket Weather Station*, you might like to watch my YouTube video showing how I assembled it, at: **https://youtu.be/ZhOhBuKC80M**

There are two types of connections to be made: power (red/black wires) and signal (green/orange/yellow wires). The charger board connects to the battery as well as all the other modules, to power them.

The only other connections required are for the I^{2}C serial bus between the Arduino Nano and the display, and one signal wire from the DHT11 to the Nano, so it can get readings.

Start by connecting the battery to the battery charging module. We aren't connecting any wires to the switch yet, because that has to be done once everything is installed in the case. You can connect the power supply wiring of the Arduino, OLED and DHT11 modules to each other, and the ground back to the charger module; leave the wires for the switch loose for now.

Try to keep the wire lengths just long enough to prevent a mess of wires later. For all the power supply connections, make sure you get the polarity correct, with black wires to the GND pins only and red wires to the positive pins. If you connect them the wrong way around, chances are good that some of the modules will be damaged.

Also, try to solder everything accurately to prevent any short circuit. It might be a tedious process, but believe me, later on it will feel worth the effort. After you have finished soldering all the components (excluding the switch), it should look something like Fig.3.

Obviously, we can't carry it around as just a collection of connected modules, so we need an enclosure for our *Pocket Weather Station* – and to give it a professional look. The best option we have is 3D printing.

The enclosure

I designed the enclosure in Tinkercad, which is a fantastic CAD software package. It supports all skill levels, so even if you are a beginner, you can still use it. You can download my 3D files (.stl format) from the November 2022 page of the *PE* website.

I don't have a 3D printer, so I used an online 3D printing service based locally (to me) in India (**www.iamrapid.com**). I uploaded my .stl files to get an instant quote and ordered the parts right away. The enclosure they delivered to me has great build quality.

Chances are you will find a similar local service. Do a web search for '3D printing service'. Even better, you might also find a nearby maker space, see: **https://bit.ly/pe-nov22-ukms** and **www.hackspace.org.uk**

Fortunately, all the cutouts that I had made in the design were in the exact spots I needed them, so I didn't have to get a second prototype made.

Putting it all together

Now, we need to place the whole circuit inside the enclosure that we designed earlier and 3D printed. It is vital that all the parts go in their respective cutouts for a neat and tidy look. It is also important that all the components are firmly fixed in their place and cannot move inside the enclosure to ensure

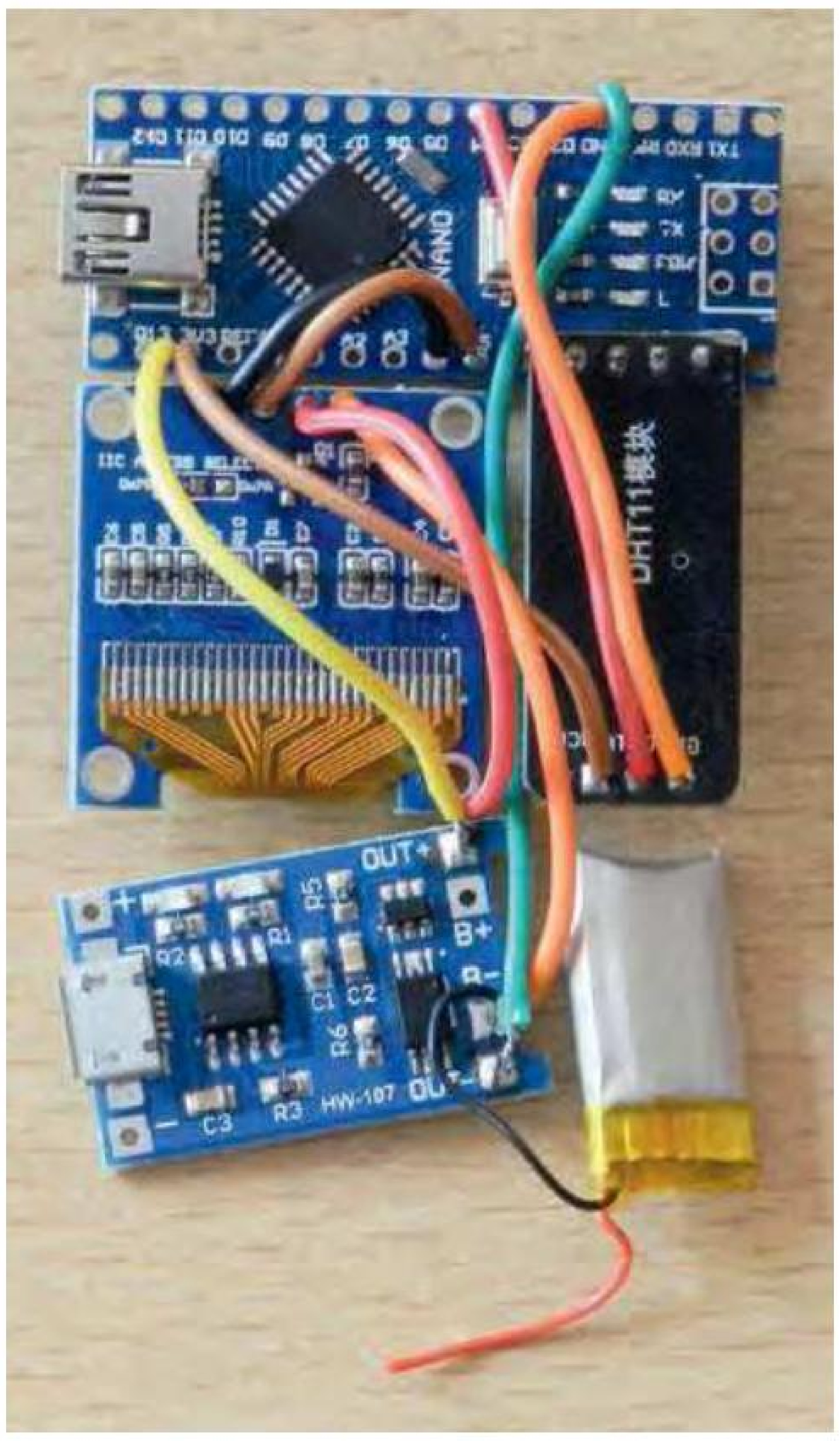
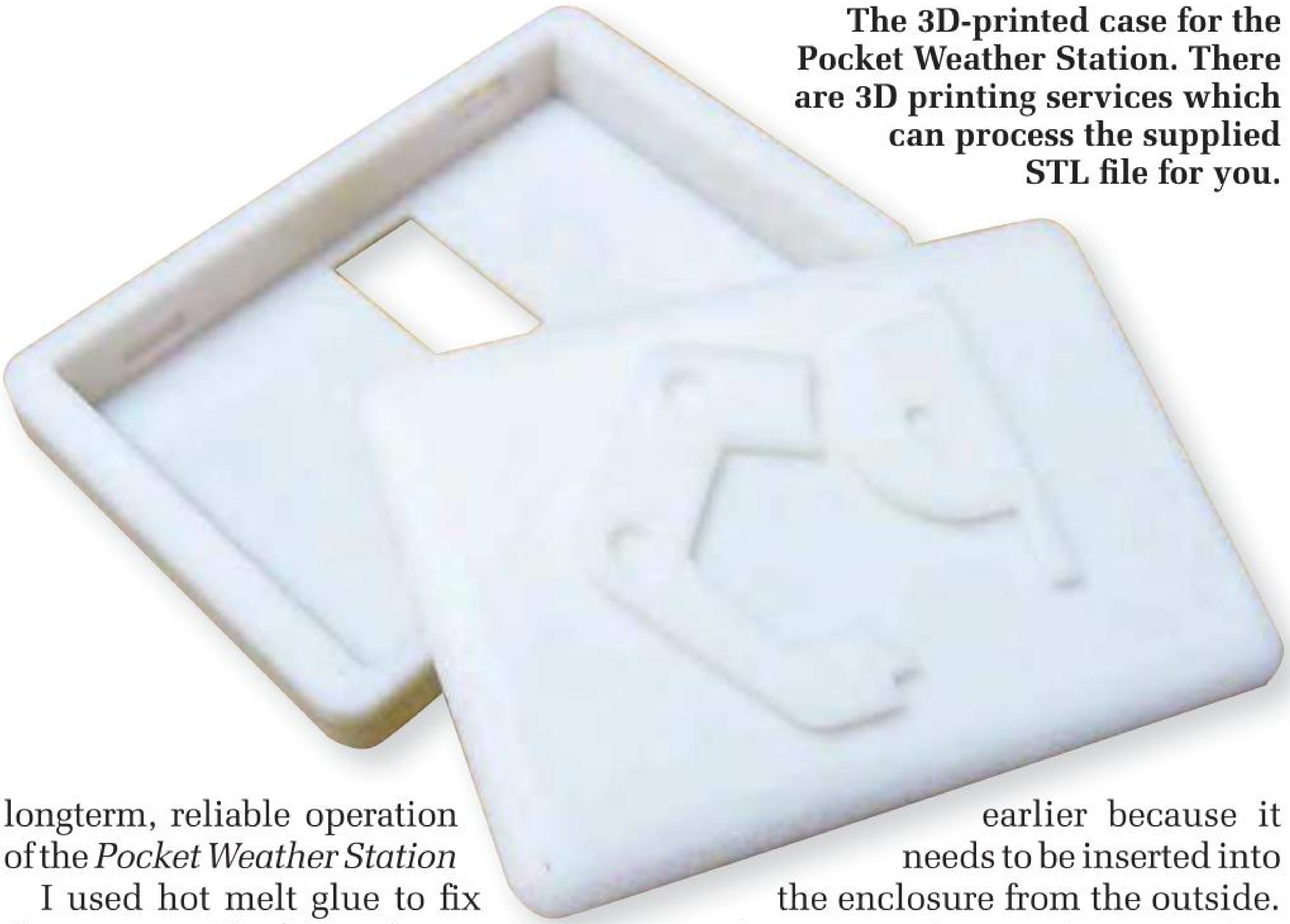


Fig.3: once you have finished wiring nearly all the components together, it should look like this.



The 3D-printed case for the Pocket Weather Station. There are 3D printing services which can process the supplied STL file for you.

longterm, reliable operation of the *Pocket Weather Station*

I used hot melt glue to fix the parts inside the enclosure. However, while this is convenient, it can fail if exposed to enough heat (eg, if it's left exposed in direct sunlight inside a car). For this reason, you could use neutral cure silicone sealant, which offers a more reliable solution. It takes longer to cure, but it's not going to fall apart if it gets hot.

As you fix the components in the case, make sure the two USB sockets line up with their access holes around the edges, as you will need to connect to both of them later.

Now it's time to add the project's slide switch into its dedicated slot. Note that we did not connect the switch earlier because it needs to be inserted into the enclosure from the outside.

After putting the switch into its slot, use two small self-tapping screws or a pair of bolts and nuts to fix it in place. Then connect its two wires: one from the V_{CC} pad of the Arduino board and one wire from the positive output of the battery charging module.

If the switch has three terminals, make sure to connect those wires to two adjacent terminals. That way, the circuit will be completed with the switch slid to the wired end.

Next, we need to complete the enclosure. I used self-tapping screws to fix the lid in place. I had already made screw holes in the enclosure design, so that was easy. Just make sure that the cover is securely in place so it looks professional and is convenient to carry. I have put my logo on the lid design to give it a nice customised look.

After closing it up, all that's left is to program the Arduino.

Programming

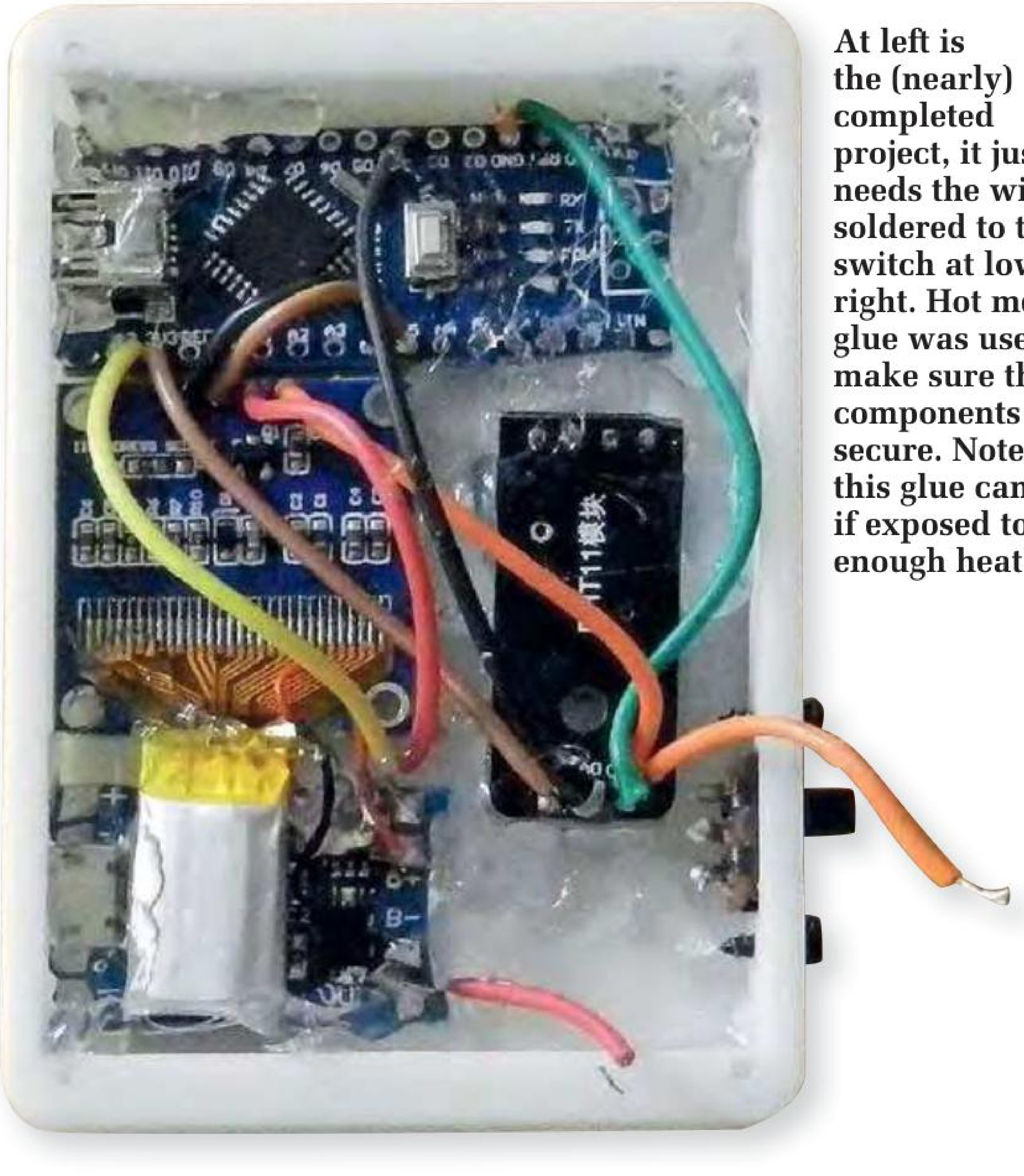
We need to upload some code to our *Pocket Weather Station*. Without code in the Arduino, our device is just a plastic box with no functionality.

First, download my Arduino sketch from the November 2022 page of the *PE* website. It is a zipped directory containing a file with a .ino file extension. Unzip the package, install the latest Arduino IDE (integrated development environment) and open the .ino file.

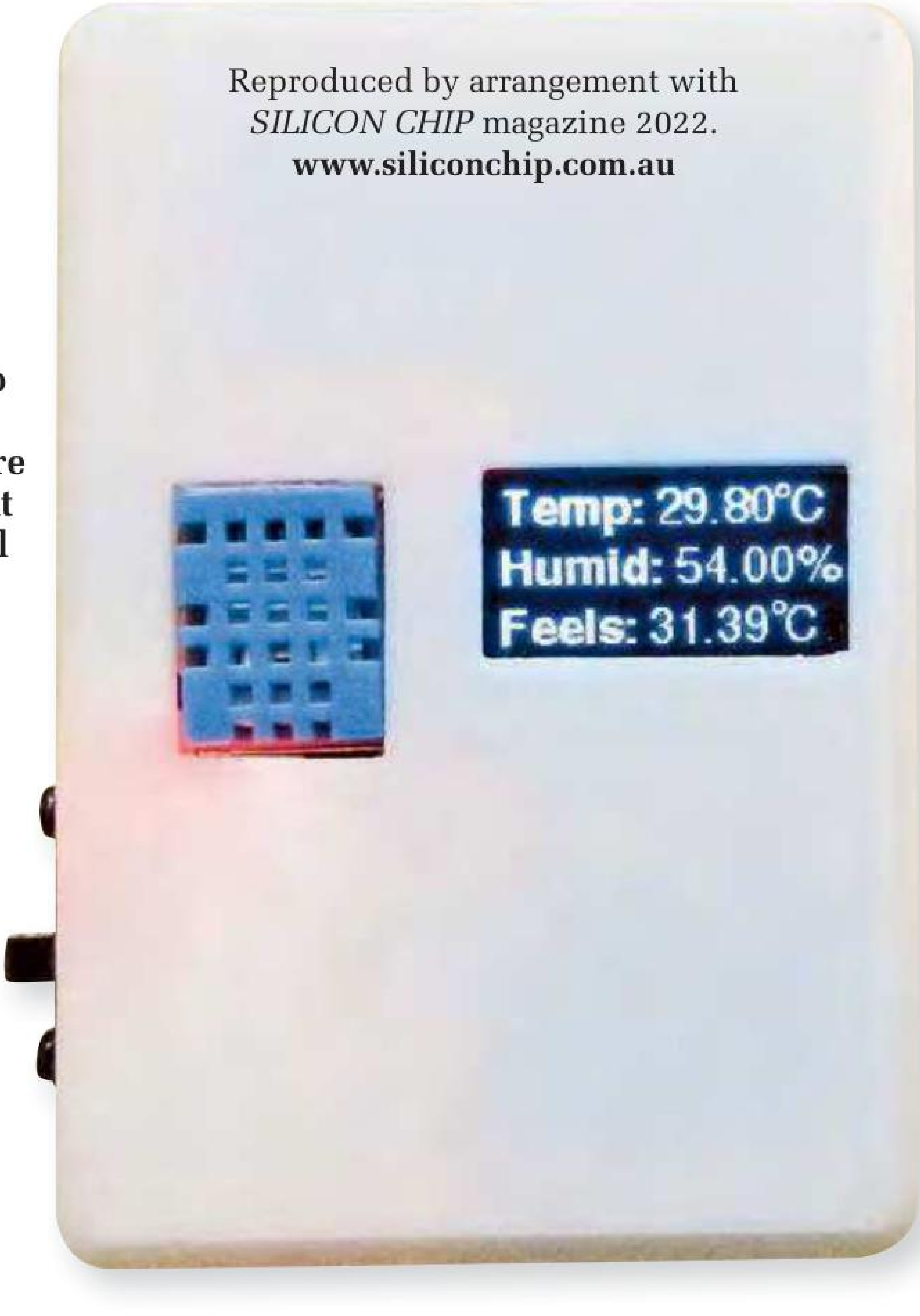
If you wish to, you can of course write the code yourself, but if you're a beginner (or even if you aren't), it's best to start with my version since we know it works. You can always modify it once you get it working. See the panel opposite if you are interested in how the code operates; that information could come in handy if you plan to make changes to it.

Once you have the code open in the Arduino IDE, plug the Arduino Nano into your computer's USB port (don't plug into the USB charger port as it does not pass data to the Arduino). Then press `CTRL+U` (or select Sketch → Upload) to compile the code and load it into the Arduino.

Check the output at the bottom of the window for error messages.



At left is the (nearly) completed project, it just needs the wires soldered to the switch at lower right. Hot melt glue was used to make sure the components were secure. Note that this glue can fail if exposed to enough heat.



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Parts List – Pocket Weather Station

1 Arduino Nano or equivalent board
1 USB cable, to suit the Nano
1 DHT11 temperature sensor module
1 0.96-inch OLED screen with I^{2}C interface and SSD1306 controller
1 TP4056 li-ion battery charging module
1 small 1S LiPo cell (eg, 160mAh)
1 slide switch
1 set of 3D printed case pieces **(optional)**
6 small self-tapping screws (two for mounting the switch, four for the lid)
various lengths of light-duty hookup wire

How the software works

The software for this project is relatively simple. Don't be daunted by the length of the code; half of it is simply the bitmap graphics for the splash screen!

The first few lines include all the libraries we will need: the graphics libraries, humidity/temperature sensor interface library, fonts and so on. It then creates the object to communicate with the DHT temperature sensor using pin D4 and another object to drive the screen with a resolution of 128x64 pixels.

Following this is the logo bitmap, then below that the main body of the code, which comprises three functions: **setup()** (for initialisation), **loop()** (the part which runs continuously after setup) and **testdrawbitmap()**, which draws the logo on the screen.

The **setup()** function starts the serial port and DHT temperature sensor communications, then initialises the display, draws the logo and pauses for one second. Once the **setup()** routine has finished (ie, after that one-second delay with the logo on the screen), **the loop()** function is repeatedly called as long as the unit has power.

Each time the **loop()** function runs, it starts by acquiring temperature and humidity readings from the DHT11 sensor, then prints that data to the serial console. It follows by clearing the screen, then printing the same information on that screen, including what the temperature 'feels like' based on the combination of temperature and humidity. It then pauses for two seconds before the process repeats.

This code is relatively straightforward, so you should be able to modify it – for example, change the way the readings are displayed on the screen – if you wish to do so.

Compilation takes a few seconds, and if it finds a problem with your code, it will tell you there. Otherwise, you should get an 'Upload successful' message, and your *Pocket Weather Station* will be fully operational.

Don't forget to charge the cell (via the other USB port) so it is ready for use. The cell charge lasts quite a long time, so you will rarely need to charge it. Now, you can proudly carry the device wherever you go and show your creation to friends (or maybe actually use it as a weather station!).

Troubleshooting

If you are here, that probably means that you have built the project, but it doesn't work yet. Don't worry, you will get it working and you will learn a lot from troubleshooting it:

1. The OLED screen is blank

You might have damaged your OLED display due to an incorrect connection, but more likely, you haven't connected the signal wires properly, so re-check them.

There might be an error in your code (perhaps you've forgotten to initialise the display). Try using my code first as you know it works, then modify it from there once you have it working.

2. All readings are 'NA'

This will happen if it can't communicate with the temperature sensor. You might have a problem with the connection between the temperature sensor to the Arduino board. Just re-check the connections. If they are correct, you might have a problem with the sensor itself – try replacing it.

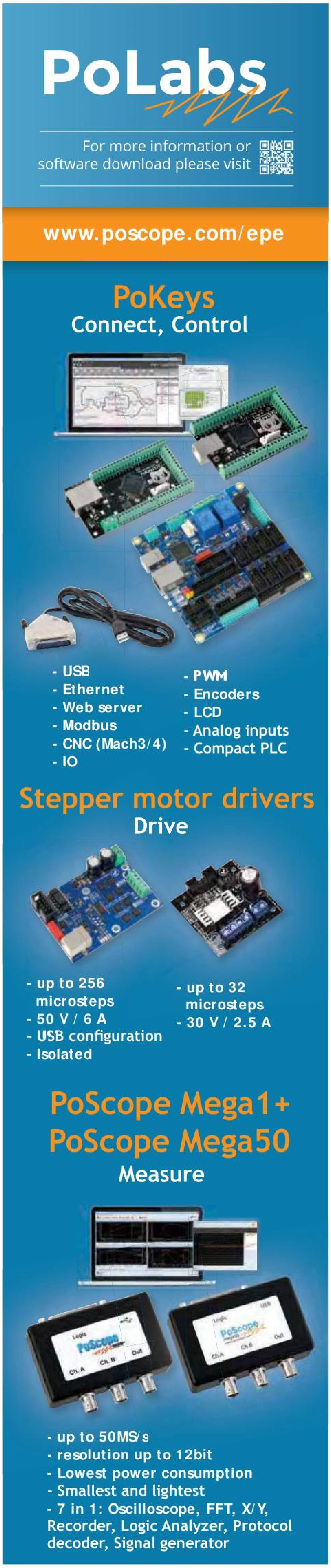
3. It works when the USB cable is plugged in, but not from the battery

If this happens, there is a problem with your battery or perhaps the connections between the battery and the rest of the circuit.

Links

This project on the Instructables website: **https://bit.ly/pe-nov22-pws1**

This project on the HackSpace website: **https://bit.ly/pe-nov22-pws2**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MODEL RAILWAY CARRIAGE LIGHTS

BY LES KERR

4472
L N E R
HEREFORD COAL Co

It's nice to have carriage lights in a model train – they add a pleasing realism to you layout. These model train carriage lights (designed for OO-gauge) are battery-powered and can be switched on and off with an external magnet.

It might seem trivial to add lights to a model railway carriage, but there are a few considerations that make it a bit more difficult than you might initially expect. One important factor is that the battery must be small, so the circuit must avoid discharging it when the lights are off. Also, you need a way of switching the lights on or off easily.

This little circuit powers five white LEDs and only draws a couple of microamps when off, and just 8mA when on. The low off-current puts a negligible load on the battery. The low 8mA operating current means that you can use two AAA batteries (cells, really) in series, giving 3V, which will power the circuit for about 100 hours. If you lack the space for that setup, you can use a single 3.7V Li-ion 800mAh battery (for example, the Jaycar **SB2300**).

The carriage size determines which batteries can be used. The circuit stops working when the battery falls below 2V.

Until recently, lights in model railway carriages were powered from the track. This is because small incandescent lamps required a relatively large current, so they couldn't be battery powered. To obtain the power, the carriage needed to have metal wheels with some form of voltage pickup attached to them, and they had to be insulated from each other.

Today, most carriage wheels are made of plastic, so they need substantial modification to pick up power from the track. Also, it isn't that easy to make a reliable pick up.

Now that efficient white LEDs are available, it is practical to power them from a small battery inside the carriage. The problem then becomes how to switch the lights on and off.

My simple solution is to mount a normally-open reed switch inside the carriage, either under the roof or on the floor. When a magnet is placed near the reed switch, its contacts close, signalling the circuit to toggle the lights on or off.

You can see a video of the prototype's operation at: **siliconchip.com.au/Videos/Carriage+Lights**

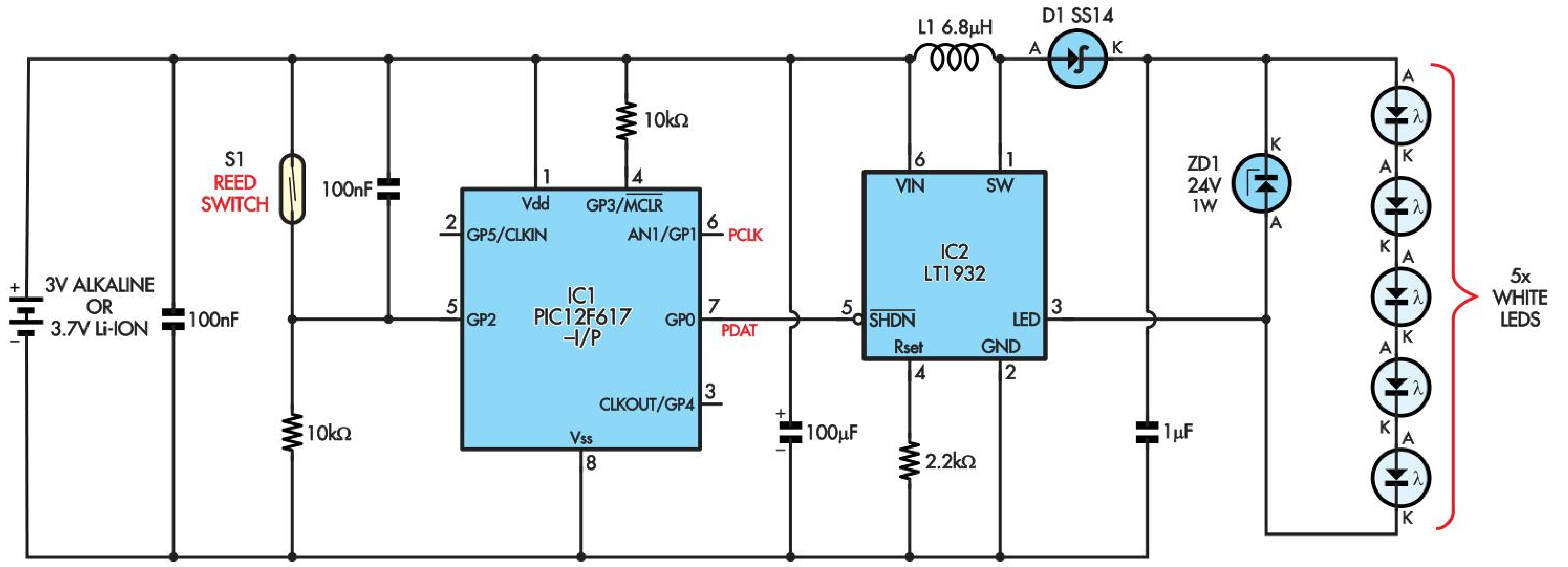
With this arrangement, you can add a magnet on the tracks just outside a tunnel so that when the train approaches, it switches the lights on. Another magnet placed near the tunnel exit switches off the lights when the train leaves the tunnel. If you want to use the train at night, you can mount the reed switch under the roof so that you can manually switch the lights on and off by waving a magnet across it.

Circuit description

Fig.1 shows the full circuit diagram. The LT1932 IC2 constant-current DC-to-DC LED driver provides a fixed current that drives the series LED lights from the battery. It is about 70% efficient and will work down to a battery voltage of 2V. It has a shutdown input that, when taken low, switches off the LEDs and reduces its current draw to less than 1µA.

I have specified high-intensity white LEDs which give adequate light when driven with 1mA. The 70% efficiency figure given above is for a 10mA LED current. To reduce this to the 1mA required without unduly affecting the efficiency, the shutdown pin is fed with a 10% duty cycle (1-to-9 mark-space ratio) PWM waveform.

The driver oscillates at 1.2MHz and uses inductor L1, schottky diode D1 and a 1µF ceramic capacitor to step up the battery voltage to the 15V or so needed by the LED string. To protect IC2 in case the LEDs are accidentally disconnected, 24V zener diode ZD1 clamps the maximum output voltage.



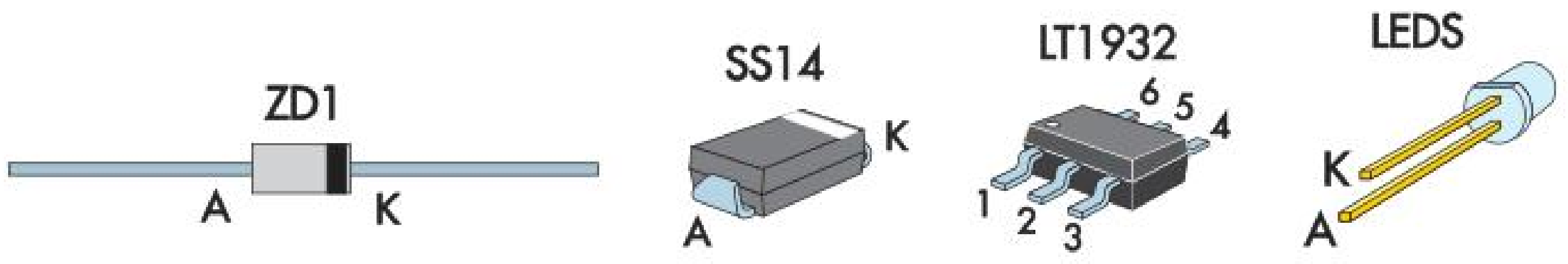


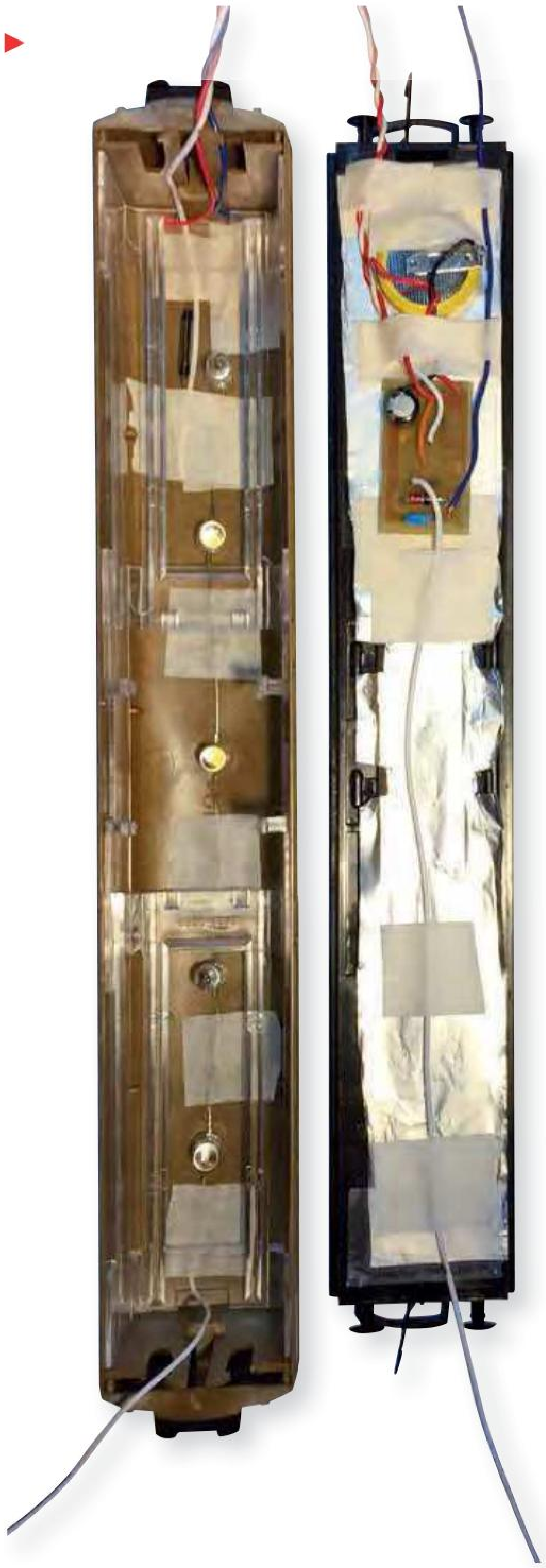
Fig.1: the Carriage Lights circuit is based on a 6-pin LT1932 (IC2) constant-current switchmode (boost) LED driver and an 8-bit, 8-pin microcontroller (IC1). The role of IC1 is twofold: it monitors the contact closure of reed switch S1 to switch the lights on and off, and when the lights are on, it drives the $\overline{\text{SHDN}}$ pin of IC2 with a 10% duty cycle square wave, reducing the LED current consumption without impacting the efficiency of the driver circuit.

The peak current through the LEDs is set to about 10mA by the 2.2kΩ resistor from IC2's R_{SET} pin to ground.

An inexpensive PIC12F617 8-bit microcontroller is used to generate the PWM waveform to drive the pin 5 $\overline{\text{SHDN}}$ input of IC2. When reed switch S1 closes, it takes the GP2 digital input (pin 5) of IC1 high. The 10kΩ pull-down resistor and 100nF capacitor help to debounce the switch contacts.

This signals the microcontroller to come out of sleep mode and provide the switching waveform to IC2, turning on the lights. If S1 is operated again, IC1 goes back into sleep mode, and its GP0 output at pin 7 goes low, switching off the lights. In sleep mode, IC1 draws about 1μA from the battery.

If you add to this the <1μA of IC2 in shutdown mode, you get a total current drain of less than 2μA, which is a negligible load on the battery.



Here is an example of how you can mount the project into a carriage. Note the clear plastic insulation under the battery and PCB. ▶

Construction

There are components on both sides of the PCB, so there are two overlay diagrams: Fig.2 and Fig.3. The *Carriage Lights Controller* is built on a 28 x 16mm PCB coded 09109211, which is available from the *PE PCB Service*. It has been deliberately kept small to fit inside a typical OO-gauge carriage.

I etched mine myself as a single-sided design, but you can get the double-sided version from the *PE PCB Service*, which avoids the need to fit a wire link. To keep the PCB small, most parts are SMDs, so it's a good project if you're interested in improving your SMD soldering skills since it has a few different types and sizes of SMD parts – but nothing especially difficult.

Programming IC1 in-circuit

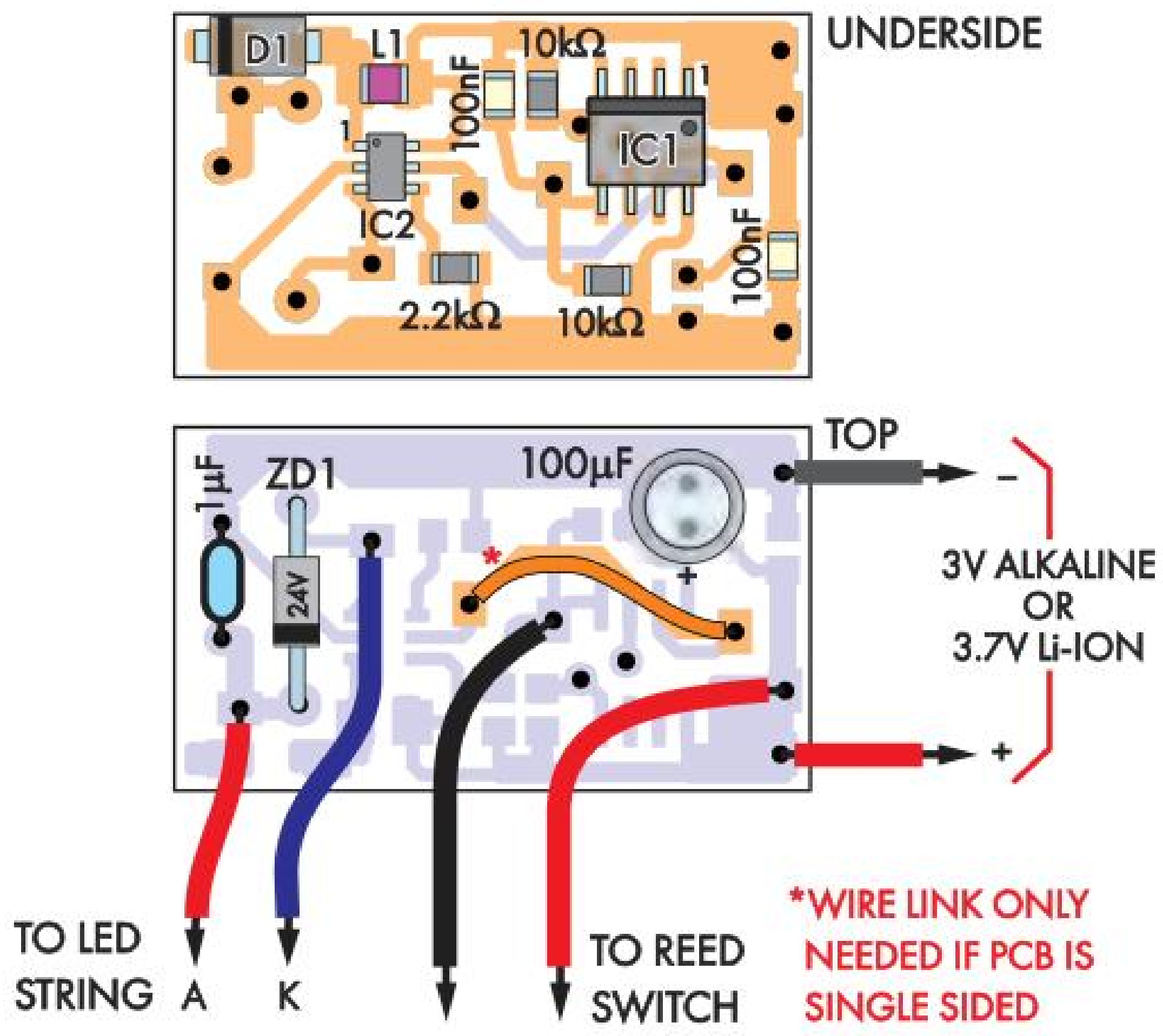
To program the micro in-circuit, you will need to solder wires to the +3V and GND battery pads (see Fig.3), as well as the PCB pads provided to connect to the PCLK pad (pin 6 of IC1), PDAT pad (pin 7 of IC1; the pad is also used for the wire link) and the $\overline{\text{MCLR}}$ pad (pin 4 of IC1).

As IC1 is mounted over the PCLK pad, solder this wire first and use as little solder as possible. Cut the part of the wire that projects from the solder joint as short as possible so that when you solder IC1, it isn't lifted above its pads.

With those wires in place and IC1 soldered to the board correctly, connect the soldered wires to your programmer. For the PICkit series, the triangle indicates pin 1, and the connections are $\overline{\text{MCLR}}$ to pin 1, +3V to pin 2, GND to pin 3, PDAT to pin 4 and PCLK to pin 5.

With those connections made, load up the programming software, open the HEX file, 'carriage lights (0910921A).HEX' and upload it to the chip.

If you are using a pre-programmed PIC12F617, it isn't necessary to solder these extra wires to the board.



Figs.2 and 3: the top and bottom side PCB overlay diagrams (shown enlarged). To save space and allow the board to use single-sided copper, all the SMDs are on one side and the through-hole parts on the other. The orange wire link does not need to be installed if a double-sided PCB is used (eg, from our Online Shop). Watch the orientations of the ICs, diodes and electrolytic capacitor during assembly.

Parts List – Carriage Lights

1 single-sided or double-sided PCB coded 09109211, 28 x 16mm available from the *PE PCB Service*
1 6.8µH 200mA inductor, SMD 2.0x1.6mm up to 2.5x2.0mm, 200mA+ <0.5Ω DCR **[RS Cat 879-0742 or Taiyo Yuden LB2016T6R8M]**
1 miniature single-pole normally-open (SP-NO) reed switch (S1) **[RS Cat 3622518 or Jaycar SM1002]**
1 magnet suitable for use with a reed switch **[RS Cat 118-7108]**
1 3V battery pack **[eg, 2 x AAA pack or 1 x 3.7V 800mAh Li-ion, Jaycar SB2300]**
various lengths and colours of light-duty hookup wire

Semiconductors
1 PIC12F617-I/SN or PIC12F617T-I/SN 8-bit microcontroller programmed with 0910921A.HEX (IC1) – code from the November 2022 page of the *PE* website
1 LT1932ES6#TRMPBF LED driver, SOT-23-6 (IC2) **[RS Cat 7618504]**
1 1N4749 24V 1W zener diode, through-hole (ZD1) **[Jaycar ZR1424]**
1 SS14 40V 1A schottky diode, DO-214AC (D1) **[RS Cat 6387915]**
5 high-intensity 3mm or 5mm white LEDs (LED1-LED5)

Capacitors
1 100µF 6.3V radial electrolytic capacitor **[RS Cat 390176]**
1 1µF 50V multi-layer ceramic through-hole capacitor **[Jaycar RC5499]**
2 100nF 50V X7R SMD ceramic capacitor, M2012/0805 size **[RS Cat 135-9033]**

Resistors *(all SMD 1% 1/8W M2012/0805 size)*
2 10kΩ 1 2.2kΩ

Perhaps unsurprisingly, the surface-mount components go on the copper side of the board, while the through-hole components are inserted from the opposite side.

The SOIC-package PIC12F617 micro will need to be programmed at some point (it is possible to program it in-circuit; see the panel below if you plan to do it that way).

Soldering

Use a flux pen or syringe of flux paste to coat IC1's leads and its associated pads. Hold IC1 in place (eg, using tweezers) with the correct orientation and use your soldering iron to tack solder one lead into place, then check that it is positioned correctly (it's also a good idea to re-check its orientation). If so, solder the remaining leads.

Clean off the flux residue and inspect the leads under magnification to ensure that all the solder joints have formed correctly. If you are not sure about any of them, add more flux and apply heat (and possibly more solder) to reflow the joint. If you have bridged any pins, use more flux and some solder wick to remove the excess solder.

Now that you've done that successfully, move on to IC2, which is slightly trickier as its pins are smaller and closer together. Since its body is also quite small, you might have trouble seeing the pin 1 indicator. You will need to make sure you've found that (eg, using a magnifier) as it must be placed with the correct orientation.

Use the same basic procedure to solder it as IC1, but keep in mind that it's very difficult to avoid bridging the pins with solder. If you have flux paste, once the part has been tacked down, you can drag-solder the three pins on the opposite side and then the three pins on the other side. Still, it's also acceptable to just solder them individually without worrying too much about creating bridges. After all, it's pretty easy to remove any bridges that have formed with solder wick, as long as you add a bit of flux to make the process go smoothly, and avoid heating the wick any more than necessary to prevent damage to the PCB.

Once again, clean the flux residue away from IC2 and scrutinise its solder joints, then go back and fix any that do not appear to have formed correctly, or are still bridged.

Now use a similar procedure to fit all the remaining SMDs, except for the 6.8µH inductor. The only remaining SMD where polarity is important is schottky diode D1; its cathode stripe should be visible on the top of the body, and this must be located as shown in Fig.2.

The inductor only has solder pads on the underside at each end, so it's harder to solder it in place compared to the other components. To enable you to do this, I made the PCB lands for the inductor larger than the component body, which means there is enough room to get your soldering iron tip in to heat them.

Coat both the lands and inductor pads with flux and lightly tin the pads with solder. Place the inductor on the PCB and apply heat from your soldering iron to the land on one side until you see the solder melt. Do the same for the other side.

Depending on how much solder you applied to the pads initially, you might want to feed a bit of extra solder into the sides while heating them.

Now make a final check of the SMD components to verify there are no solder bridges or shorts, and if there are, fix them up with a bit of flux paste and the solder wick.

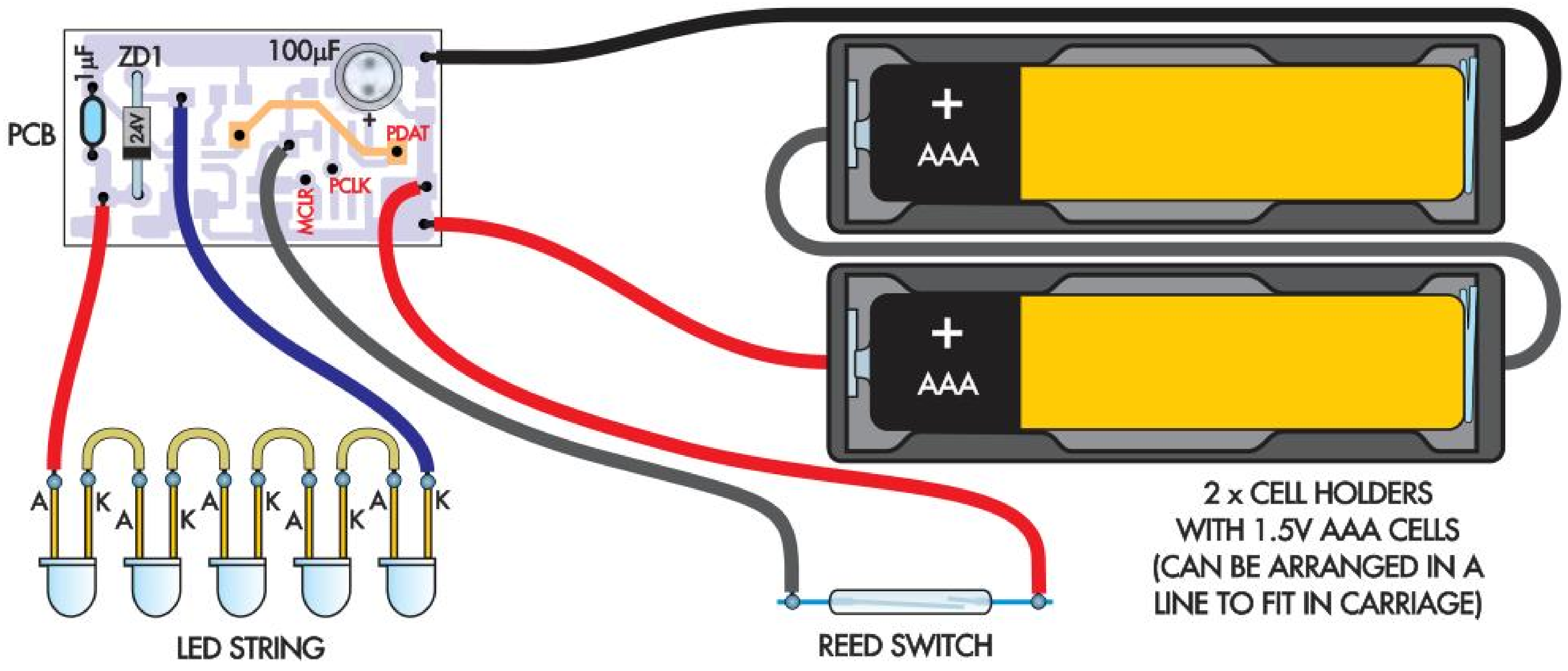
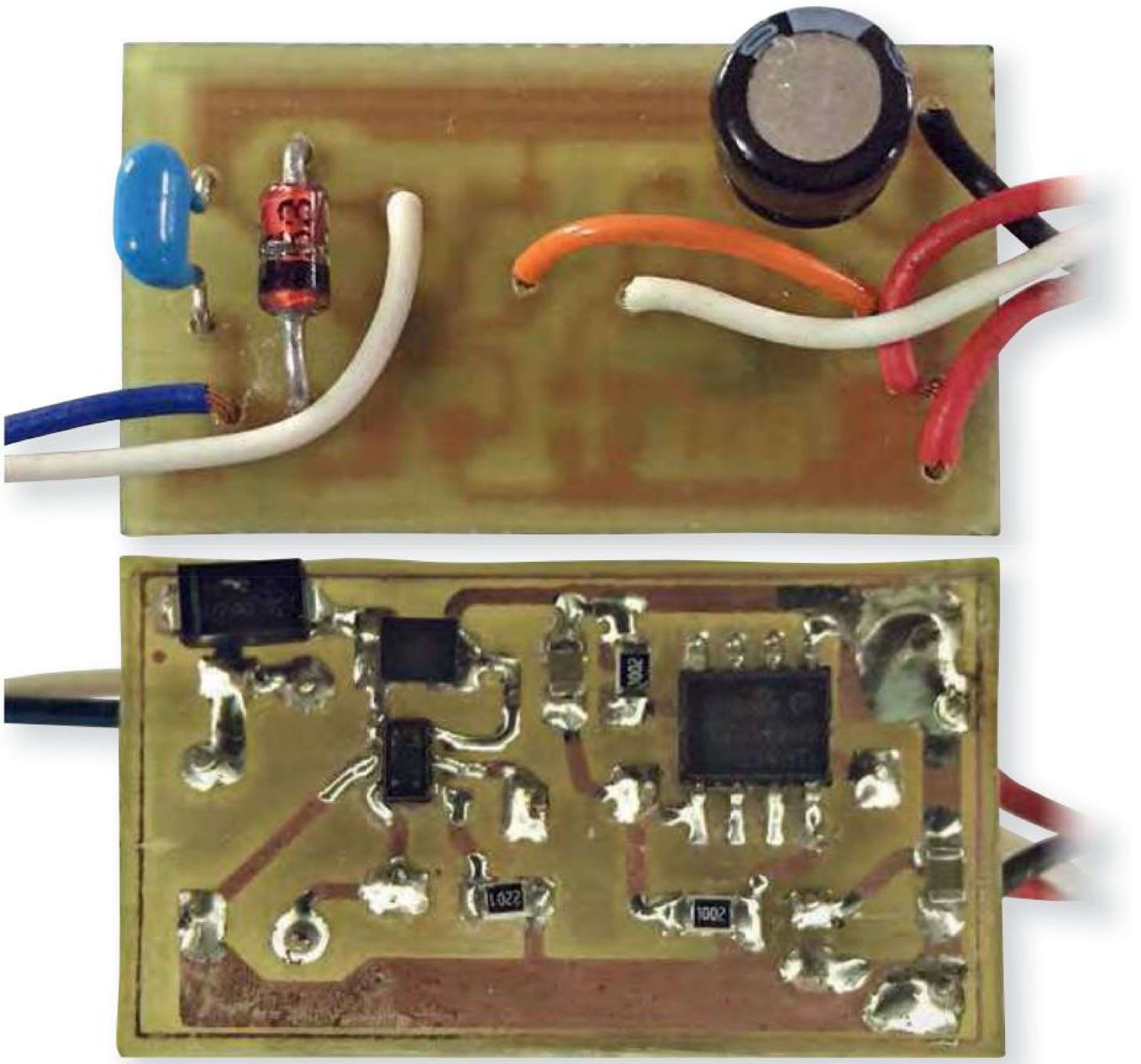

PCB
1µF
ZD1
24V
100µF
+
PDAT
PCLK
MCLR
+
AAA
+
AAA
A K A K A K A K A K
LED STRING
REED SWITCH
2 x CELL HOLDERS WITH 1.5V AAA CELLS (CAN BE ARRANGED IN A LINE TO FIT IN CARRIAGE)

Fig.4: there are just three items to wire to the board; the power supply (in this case, a 3V battery pack using two AAA cells), the reed switch and the string of white LEDs. You can use just about any type of white LED as long as the voltage required to power the string is in the range of about 5-20V. Various LED mounting arrangements are possible, too – whatever suits your carriage(s).



Here are both sides of the finished project shown greatly enlarged for clarity. While you can definitely etch the single-sided board yourself given the right supplies, we will be selling a double-sided version for convenience.

Turn the board over and solder in the wire link (if you are using a single-sided board), zener diode, 1µF ceramic capacitor and the 100µF electrolytic, making sure the diode and electrolytic capacitor are the right way around. These components are all shown in the underside overlay diagram (Fig.3).

Wiring it up

While Fig.3 shows the basic external wiring connections, there are more details shown in the wiring diagram (Fig.4). So that you can work out the length of the board connecting wires, you need to decide how and where the components fit into the carriage.

In my case, I glued the LEDs and the reed switch to the underside of the carriage roof and taped the battery and PCB to the floor of the carriage. If you have a smaller carriage, you might prefer to use 3mm LEDs. Another solution for the LED mounting is to solder them to a thin strip of Veroboard which can be attached to the underside of the roof.

If the floor of your carriage is black (like mine) you can improve the radiated light by covering it with aluminium foil to reflect the light back up. If you do this, insulate the PCB with tape so that none of the tracks short out on the foil.

Once you have decided on the layout, cut the wires to length and solder them to the PCB.

Testing

Connect up the reed switch and LEDs, and before connecting the battery, have a last look at the board for faults or dry joints. Ensure you connect the battery the right way around – the circuit will be destroyed if you don't.

Now place the magnet parallel to the reed switch a few millimetres away; the LEDs should light. Remove the magnet, then put it back where you had it, and the LEDs should extinguish.

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By Jim Rowe

Self-Contained 6GHz Digital Attenuator

ON
ATT=-21.75DB
Fre=6,000,000KHz
GND
+
OK
-

This new digitally programmable module can attenuate signals from 1MHz to 6GHz by 0 to 31.75dB in 0.25dB steps. You control it using five small pushbutton switches, while a tiny OLED screen shows the current setting.

I recently reviewed a new and small digitally-programmed UHF step attenuator module that could attenuate signals from 1MHz to 3.8GHz by 0-31dB in 1dB steps (October 2022). It has an inbuilt microcontroller, and the attenuation is set using four small pushbutton switches.

The results were quite respectable overall, although there seemed to be a bit of contact bounce with the pushbutton switches and the RF output and power input connectors were too close together.

As I finished writing that review, I became aware that a slightly larger digital attenuator had become available, with a broader frequency range and 0.25dB attenuation steps rather than 1dB.

New module

The new module is likely available from several suppliers on the web, but I ordered the one shown in the photos from Banggood, catalog code 1648810. Currently, it's priced at around £25 with free shipping to the UK. Like the earlier 3.8GHz module, it's almost certainly made in China.

The new module measures 56 x 40 x 16mm overall, not counting the SMA connectors at each end for RF input and output.

The digital attenuator section is on a small PCB fitted down inside a 56 x 40 x 10mm CNC machined aluminium block which forms the module's 'case'. The rest of the module's circuitry is mounted on a second PCB measuring 56 x 40mm, which forms the top of the case.

The OLED panel is mounted on the top of this PCB in the centre, along with the micro-USB power socket, the mini slider power switch and a tiny SMD power LED. Then along the PCB front are the five small pushbutton switches used to select the attenuation setting. Presumably, the rest of the controller circuitry is mounted on the underside of this PCB.

The UHF attenuator chip is probably the Analog Devices HMC1119, a 'big brother' to the HMC472 used in the aforementioned 3.8GHz attenuator.

According to the Analog Devices data sheet, the HMC1119 has a range of 100MHz to 6.0GHz and seven control bits, giving a setting range of 0 to 31.75dB in 0.25dB steps. It has a specified insertion loss of 1.3dB at 2.0GHz, drooping to around 1.5dB at 3.5GHz and a whisker below 2.0dB at 6GHz. – all in all pretty impressive!

As with the 3.8GHz attenuator, I couldn't find a full circuit for the new module, so I could only work out a basic block diagram for it, shown in Fig.1.

The RF1 input and RF2 output pins of the HMC1119 chip are coupled to the SMA input and output connectors via capacitors. Apart from various bypass capacitors, that makes up all of the actual attenuator section.

Below is the control section, based on a microcontroller (possibly an STM32F103C8T6, like the one used in the 3.8GHz attenuator).

Operation

The microcontroller (MCU) controls the attenuation settings of the HMC1119 via the seven programming lines, while the user determines the attenuation setting using the five small pushbutton switches S1-S5. To make this easy, the MCU displays the current attenuation setting on the OLED screen, controlled using a standard I^{2}C serial interface.

When power is first applied, the MCU sets the attenuation to 00.00dB. To change this, you first press S3 (the OK button) and then press S1 (<) or S5 (>) until the display is flashing the setting

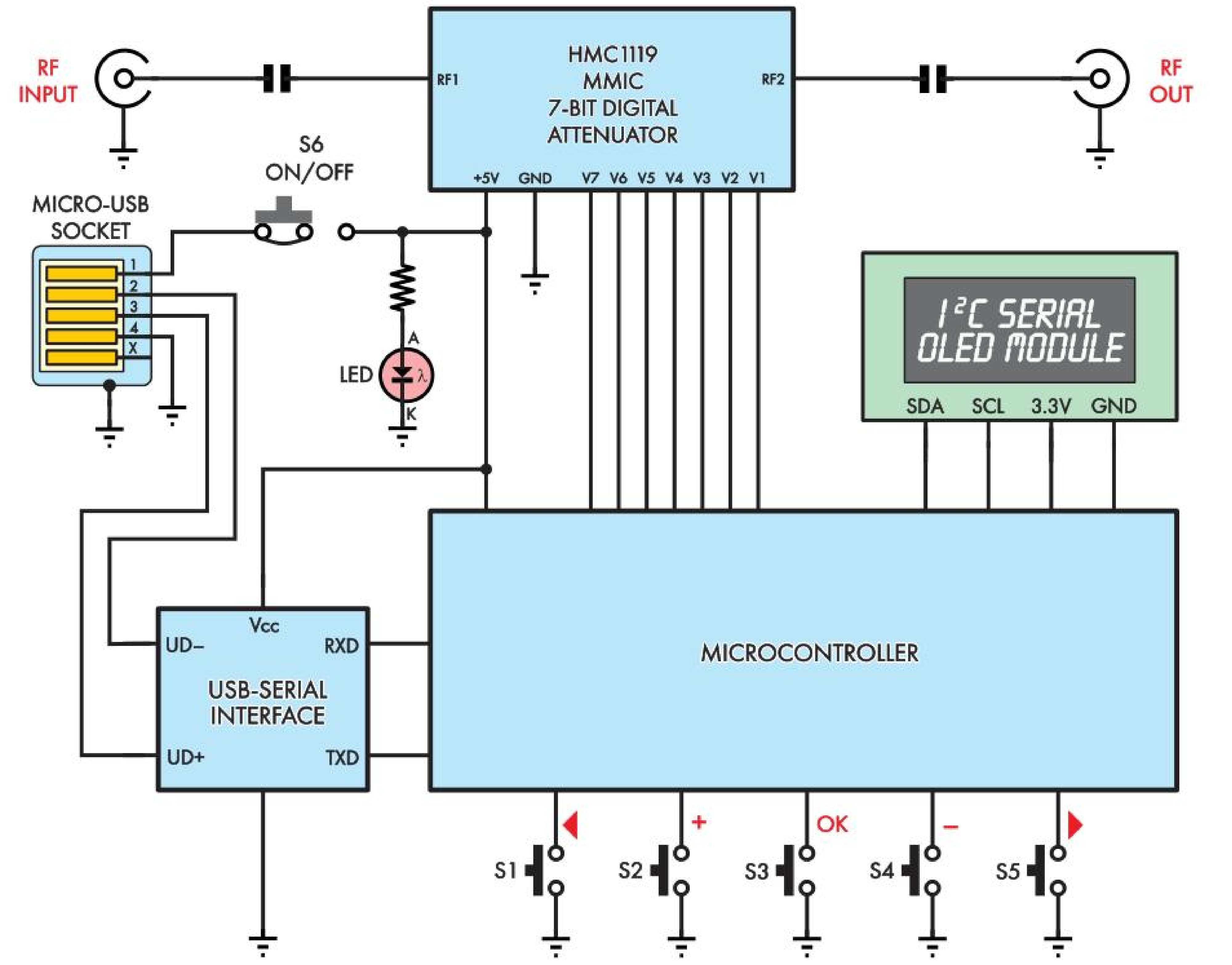

Fig.1: no full circuit diagram of the 6GHz attenuator available – this simplified version is what we expect the block diagram look like.

digit you want to change. Then you can press either S2 (+) or S4 (-) to change the value of this digit. To change other digits, use either S1 or S5 to move to them, then use S2 or S4 to change their value. Then if you press S3 again, this will be the new setting.

It's pretty straightforward, and although the tiny pushbuttons used for S1-S5 seem to be the same as those used on the 3.8GHz module, the additional two buttons seem to allow the setting to be changed more reliably. Perhaps the firmware in the MCU has also been improved to make it less susceptible to contact bounce.

I have also shown a USB-serial interface chip in Fig.1. This chip may or may not be in the 6GHz module; I've shown it purely because it was present in the 3.8GHz module. It's possible that, in this case, the data lines from the micro-USB connector go directly to two pins of the MCU, but they certainly are routed somewhere on the PCB.

Either way, it would allow the attenuation setting to be programmed from an external PC, as well as from its own 'keyboard'. So the micro-USB socket is not just to feed power to the module, but also for external control.

As with the 3.8GHz attenuator, there's virtually no information provided on doing this external control, but I found a very cryptic suggestion in the 'Customer Q&As' section of the Banggood info on the module: 'Go to **github.com/emp-temp/att6000_control** for Python code.'

I'm not familiar with the Python programming language, so I sought help from colleagues who do use it. They advised me that all the **att6000** Python code seemed to do was send serial text commands in the format `wv0XXYY<LF>`, where the `XXYY` characters indicate the desired attenuation setting `XX.YY`.

In other words, sending the command `wv02375<LF>` should change the attenuator's setting to –23.75dB.

They also informed me that the command should be sent at 115,200 baud, not the 9600 baud that seemed to be used previously. I did try this out, and the results are described below.

Performance

I measured the performance of the new attenuator module using my Signal Hound USB-SA44B HF-UHF spectrum analyser and its matching USB-TG44A tracking generator. Both were controlled by Signal Hound's Spike software (V3.5.15) in its SNA (scalar network analysis) mode.

Since the SA44B and TG44A combination will only work up to 4.4GHz, I could only check the module over this range.

ATT=-21. 75DB
Fre=6, 000, 000KHz
GND
RXD
TXD
3.3V
NO
ATT-6000-30DB

The 6GHz digital attenuator from Banggood has an OLED screen and weighs about 57g.

I first used this setup to check the module's performance at an attenuation setting of 00.00dB to see its insertion loss. This is shown in Fig.2; the measured insertion loss is less than –2.5dB up to about 1.3GHz, then droops down to about –6.0dB at 2.5GHz, then improves to about –2.5dB at 3.0GHz.

It then droops to about –4.5dB at 4.0GHz, before moving up again to reach –4.0dB at 4.4GHz, which looks promising for its insertion loss at frequencies up to 6GHz.

After this, I did response tests at 'major' attenuation steps: –5dB, –10dB, –15dB,–20dB, –25dB and –30dB. These settings were chosen to give a good idea of the module's overall performance. After examining the results I then checked the response at a number of 'fine detail' settings: –1dB, –1.5dB, –2dB, –3dB, –4dB, –7.5dB, –10.75dB, –14dB, –19dB, –28.25dB and –31.75dB.

During each of these tests, I saved an image of Spike's plot of the test results. Then, knowing that there wouldn't be enough space to reproduce all 18 of the plots separately, I combined all of the plots into a single composite plot, to allow for easier evaluation – see Fig.3.

The upper plots in Fig.3 (down to about –20dB) have a shape almost identical to that of the top 00.00dB plot, just separated from it by the chosen attenuation setting.

For frequencies above about 1.75GHz, the higher attenuation plots (–20dB and greater) develop an increasing number of bumps and dips. These are very apparent in, for example, the red –25dB plot, the purple –28.25dB plot, the red –30dB plot and the blue –31.75dB plot.

All of these four plots show an increasing tendency to have a significant dip between 2.5GHz and 3.1GHz. I suspect that this may be due to small resonances inside the HMC1119 chip and/or its surrounding tracks on the attenuator section's PCB. There might also be standing waves inside the attenuator box at specific frequencies.

These plots tell us that the attenuator's performance is quite respectable, at least for frequencies up to about 2.2GHz and for settings up to about –20dB. But the errors do increase for frequencies above 2.2GHz and with settings above –20dB.

Of course, the attenuator would still have many practical uses at frequencies above 2.2GHz and with settings above –20dB, especially if you were to use Fig.3 to correct for likely errors.

Armed with the information mentioned earlier on how to control the device over a serial connection, it didn't take me long at all to test sending new attenuation settings from my Windows 10 PC, using the TeraTerm serial terminal application.

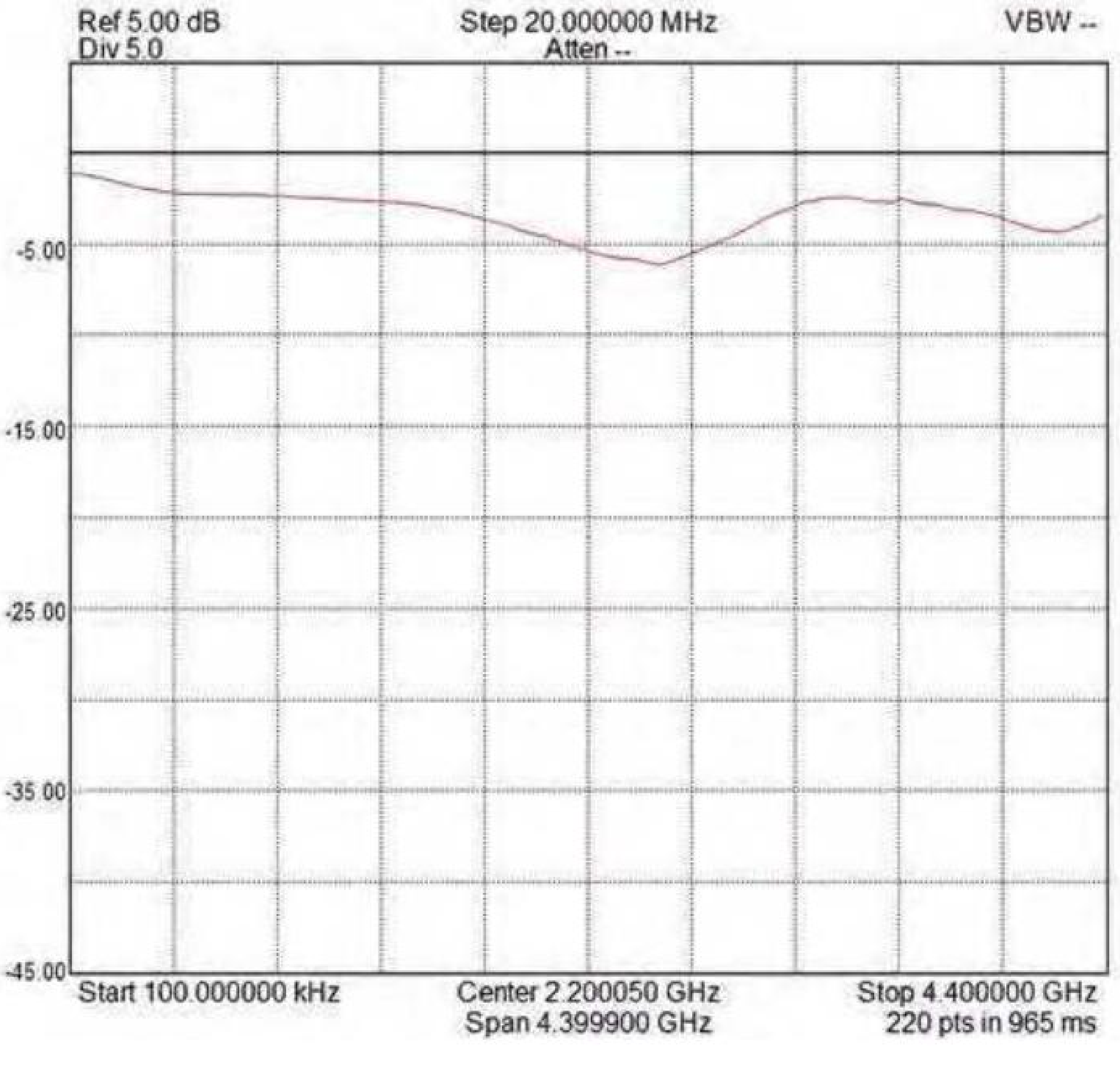

Fig.2: using Signal Hound's Spike software the 6GHz module could be checked at an attenuation setting of 0dB to measure its insertion loss. Note that the setup used for testing can only measure up to 4.4GHz, so not the full quoted range of the attenuator.

assigned. Then I started up Tera-Term and set it up to communicate with that port at 115,200 baud, with the 8N1 data format and with only an LF (line feed) at the end of each line.

I was then able to change the attenuator's setting at any time simply by typing in a command like `wv01575` and pressing the Enter key. No problem! The attenuator's OLED immediately showed the new setting (for example: '–15.75dB') and also sent back an 'OK' message, to confirm that the command had been received and acted upon.

I should perhaps note that there does seem to be provision on the top of the attenuator (just to the left of the OLED) for connecting a separate serial interface, as you can see in the photos. But there's no information on doing this. I guess that the command interface is the same, but I haven't tried it, so I can't say for sure.

Conclusions

Overall this new attenuator module seems reasonably good value for money when you consider its relatively wide frequency range and low price. I also like its ability to be programmed using the built-in MCU, control buttons and tiny OLED screen, or from a PC via the USB port (and presumably from a separate microcontroller, via the serial port header).

My only real gripe is that when I tried to unplug the USB cable from the micro-USB socket after testing it, the socket lifted straight off the PCB. It seemed to have been poorly soldered, and as a result, I had to spend quite a bit of time soldering it back on (under a microscope). I'd have preferred a mini-USB socket, as these seem to be a bit more rugged and also attach more securely to the PCB.

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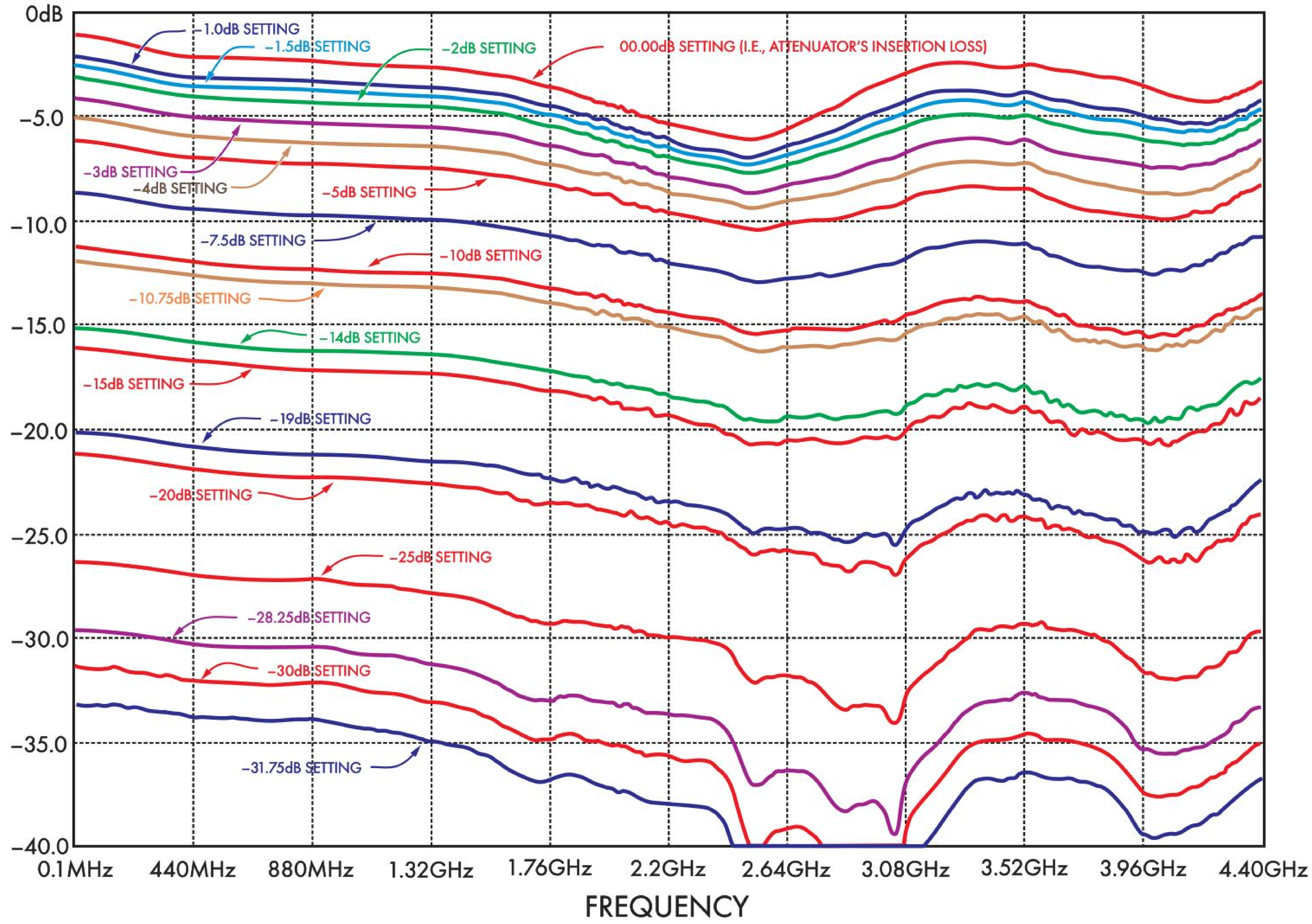


Fig.3: a graph showing the combined result from a variety of response tests on the attenuator at various settings.

Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 41: Self-contained PicoMite computer

This month, we will show how easy it is to attach a TFT display and a PS/2 keyboard to a PicoMite, resulting in a standalone computer that can be compared to the popular MaxiMite Computer. Two versions of the MaxiMite have been featured in *PE* (November 2019, and October 2021) and it must be stressed that this PicoMite version is by no means a replacement for either of them. So why create it? Well, there are two main reasons; the cost of parts used is much lower than those required for either MaxiMite version, but more importantly, the PicoMite computer uses parts that are readily available (yes, the main chips for the MaxiMite are still pretty much unavailable due to ongoing global supply chain issues).

Just six modules are required to build the PicoMite computer:

1. PicoMite
2. SSD1963 TFT module
3. PS/2 keyboard
4. Level shifter (so the 5V keyboard doesn't damage the 3.3V PicoMite)
5. PS/2 breakout board (to connect the keyboard to the level shifter)
6. 5V USB power supply (to power all the computer parts).

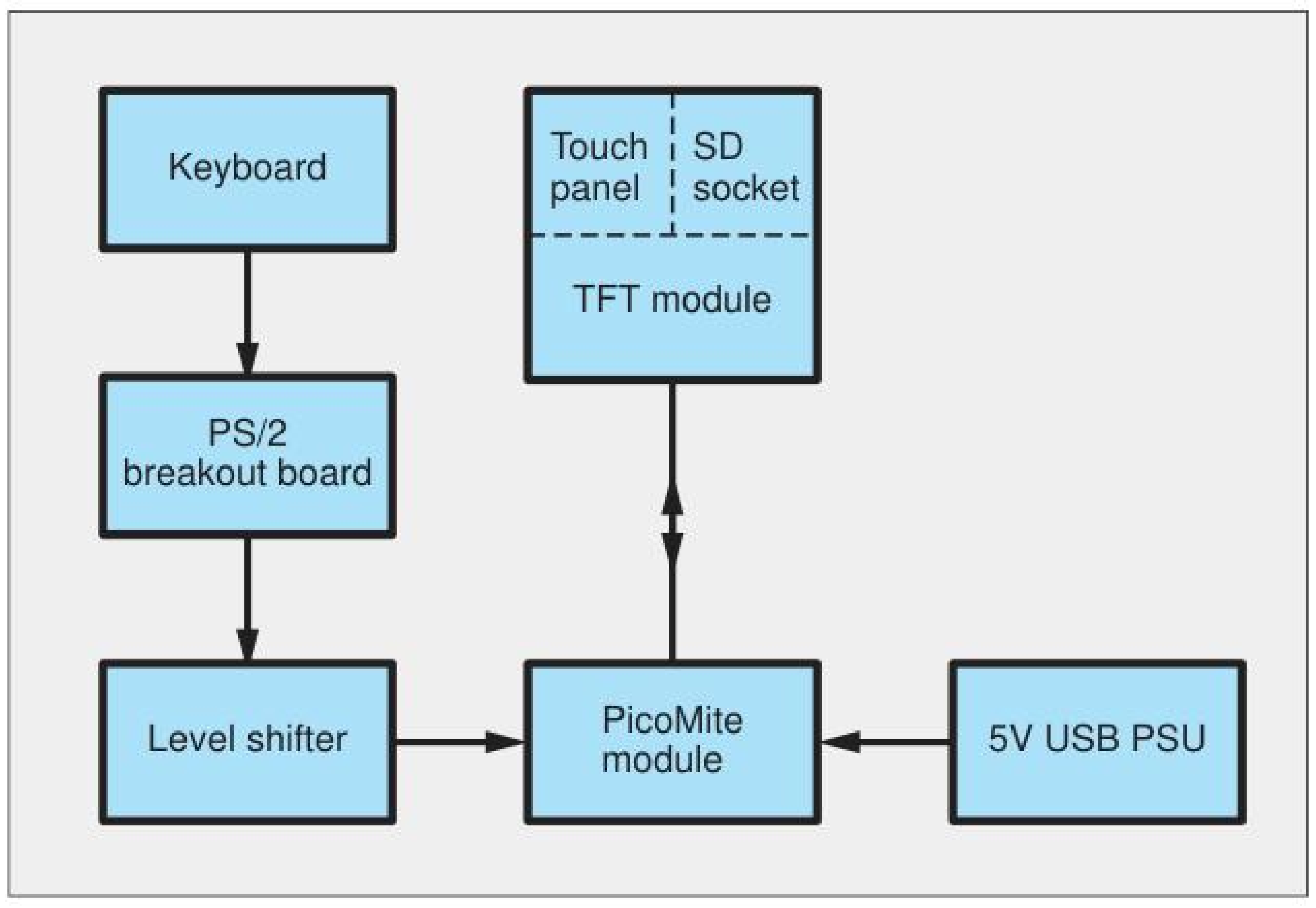
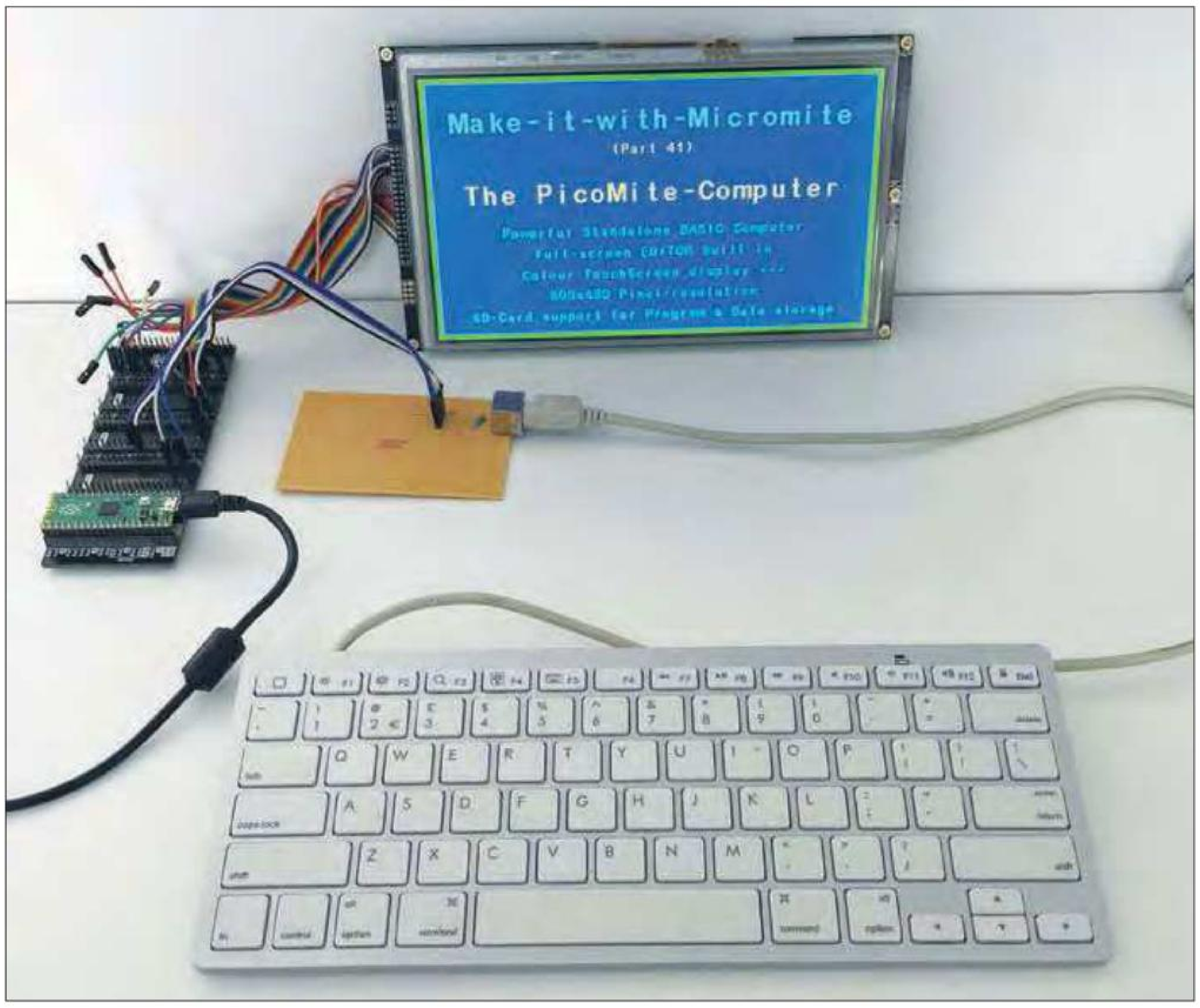


Fig.1. Overview of how the six modules connect together in the PicoMite computer.



An easy-to-build PicoMite computer.

An important detail worth noting at this point is that SSD1963 display modules typically have an onboard micro-SD card socket. This means, with an appropriately sized SD card, it can be used as the storage drive for our PicoMite computer.

Also, these displays can optionally be purchased with a resistive touch panel. Depending on your requirements, a large touchscreen can make a nice user interface.

So, with the above six modules, we can easily build a low-cost, modern-day version of an 80s home computer with an impressive 800x480, full-colour display.

The PicoMite

To see an overview of how all the different elements are connected, please refer to Fig.1. The PicoMite module is the heart of the computer. If you are following this series (at least for the last few articles), you are likely to have a PicoMite module already. If not, then grab one, or ideally several; they cost under £4 each and are readily available from many online stockists.

No special firmware is used for this computer, simply ensure that you load the latest version of the PicoMite firmware which is available for free download from: **geoffg.net/picomite.html**

At the time of writing this article, the file available was **PicoMiteV5.07.04.uf2**. For details of how to install the

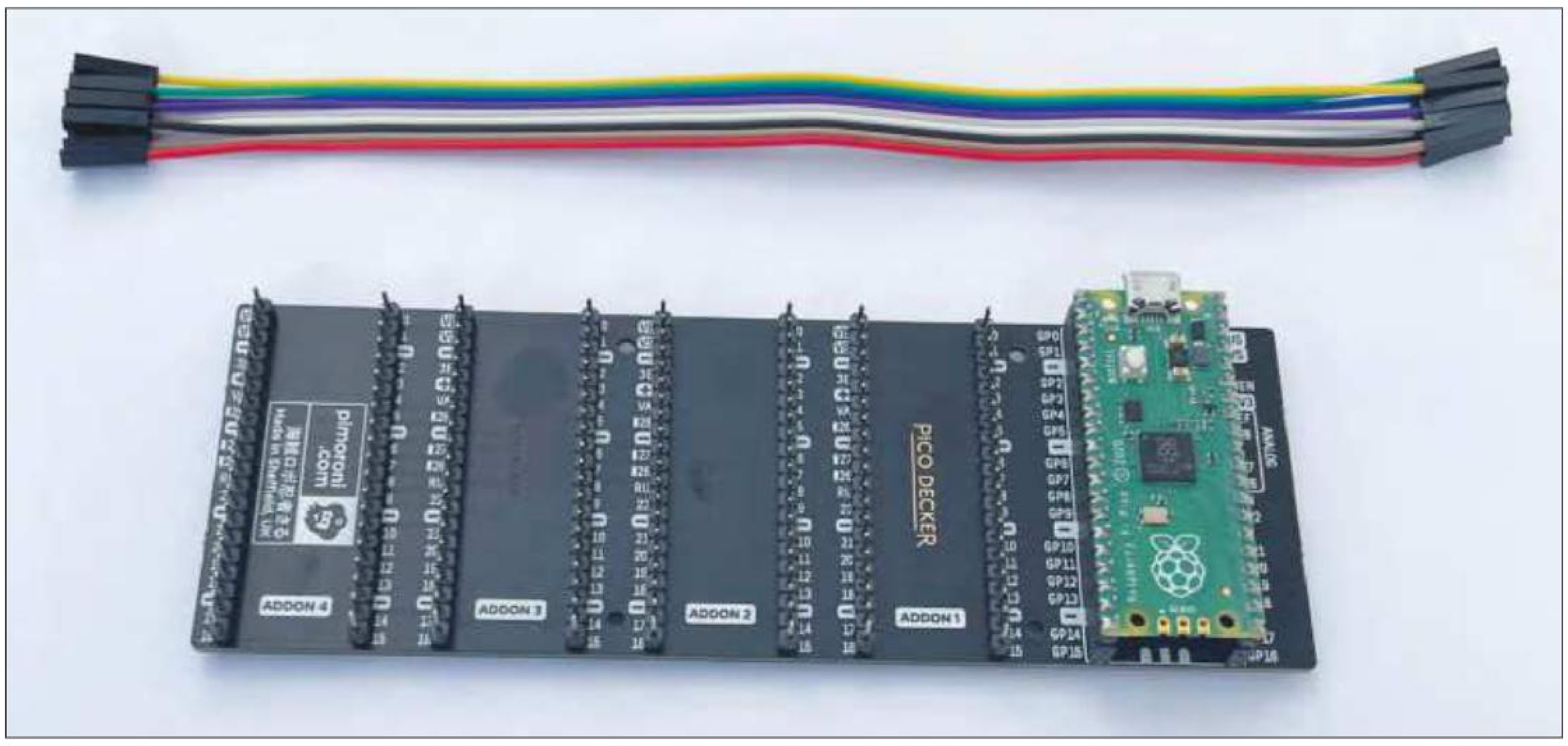


Fig.2. Mounting the PicoMite onto a Pico Expansion Board will make it easier to connect the other modules. To implement these connections, we use female-to-female DuPont leads.

firmware file, please refer to *Make it with Micromite, Part 37 – PE*, July 2022, p.42-44, or the *PicoMite User Manual* (also available at: **geoffg.net**). The whole process takes just a couple of minutes to complete.

Note that we will be connecting the PicoMite to the other modules with DuPont leads. To make this whole process easier, we recommend inserting the PicoMite into a Pico Expansion board (see Fig.2 and refer to *Make it with Micromite, Part 38 – PE*, August 2022).

Choosing an SSD1963 TFT module

If you perform an online search for 'ssd1963 touch tft module', you will see that there are many different types available. Our preferred supplier is **buydisplay.com** (no affiliation) – they always have a good range of products available at sensible prices, although shipping from China must be added to the cost of the screen.

A word of caution here is that you need a complete TFT module rather than just the glass-panel display. Simply check that the display you are choosing includes a PCB of identical size to the screen – the screen attaches to this PCB, which in turn provides connections to the outside world, as well as containing the onboard SD socket. If all you see is a glass panel with a flexible ribbon-cable, then this is not the required item. Another word of caution concerns the pinout of the main connector which the PicoMite connects to. There is no 'standard' pinout, however, they all have the necessary pins required, albeit potentially with slight variations in naming convention. Again, please refer to the *PicoMite User Manual* for more information.

There are various points to consider when choosing an SSD1963 TFT module. The first thing is the size of the display you want to use. They are available in 4.3-inch, 5-inch, 7-inch, 8-inch, and 9-inch variants. Unsurprisingly, the bigger the screen, the higher the cost (around £25 for the 4.3-inch, up to around £60 for the 9-inch). We recommend getting the biggest screen possible as it makes it a much more pleasant experience when writing program code. Essentially, the bigger the screen, the bigger the characters on the screen and thus the easier it is to read and check code. For this article, we have used the 9-inch screen, which results in a 'laptop-like' experience. The link to the exact 9-inch display I used is: **https://bit.ly/pe-nov22-9in**

So, having searched for a suitably sized SSD1963 TFT module, you will likely see some options available when proceeding to purchase it. In summary, you need to take account of the following:

- The module should have a parallel 8080 Interface (rather than 6800)
- Check that a pin header is included (rather than FFC)
- Module uses a 3.3V power supply, as opposed to 5V
- If you want to have the touch option then select 'resistive touch' (rather than 'capacitive touch')
- You may see an option for a 'Font chip' – there is no need to select this as it isn't used
- There may be an option for the SD-socket connector – select 'pin header' (not FFC).

Backlight control

When the screen arrives, there is one modification that is likely to be required; this concerns the backlight. Depending on the screen size, typically there are soldered jumpers on the back of the display module that select how the backlight is controlled. By default, the 'LED-A' option is typically shorted, possibly with a 0Ω resistor (see Fig.3). This short needs to be removed, and the '1963-PWM' (or equivalent) option shorted instead. This modification allows the PicoMite to control the backlight brightness via the `BACKLIGHT` command.

Connecting the TFT module

Once a suitable screen arrives, and you've made the backlight control modification, the TFT module can now be connected to the PicoMite. To get things up and running quickly, we simply used 30cm female-to-female DuPont leads between the TFT module's pin-header and the Pico expansion board. Note that stripboard can be used for a more permanent setup, but we have not done that here due to the various pin outs that exist across the different SSD1963 modules.

The required connections are listed in a table in the *PicoMite User Manual* – however, we have recreated those details in Fig.4. Now make the connections shown in black, being careful not to dislodge any of the previously attached DuPont leads. Depending on the exact screen used, there are around 15 connections to make (not forgetting power too). Please ensure you visually check everything as you proceed to eliminate any errors.

Testing the display

To test that the display is connected correctly to the PicoMite, use a USB cable to connect the PicoMite to your laptop/PC, and launch your preferred Terminal app (I like to use TeraTerm). At the command prompt, begin by resetting all options by typing `OPTION RESET`. Then, depending on the size of the screen (see *User Manual*), type the following commands:

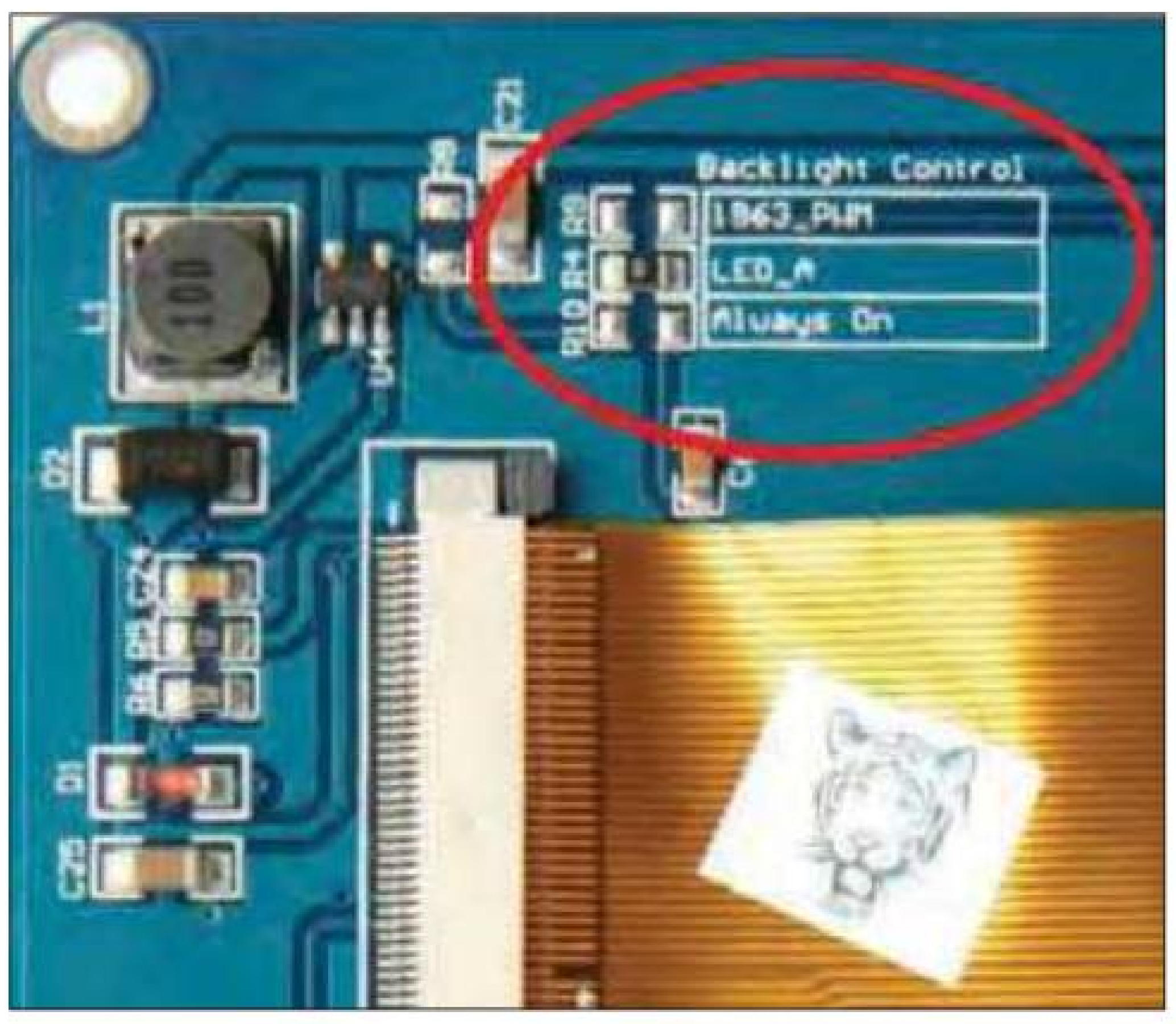


Fig.3. On some SSD1963 tft modules, you may need to modify the backlight control. If applicable, remove the 'LED-A' short, and ensure the '1963-PWM' link is shorted instead.

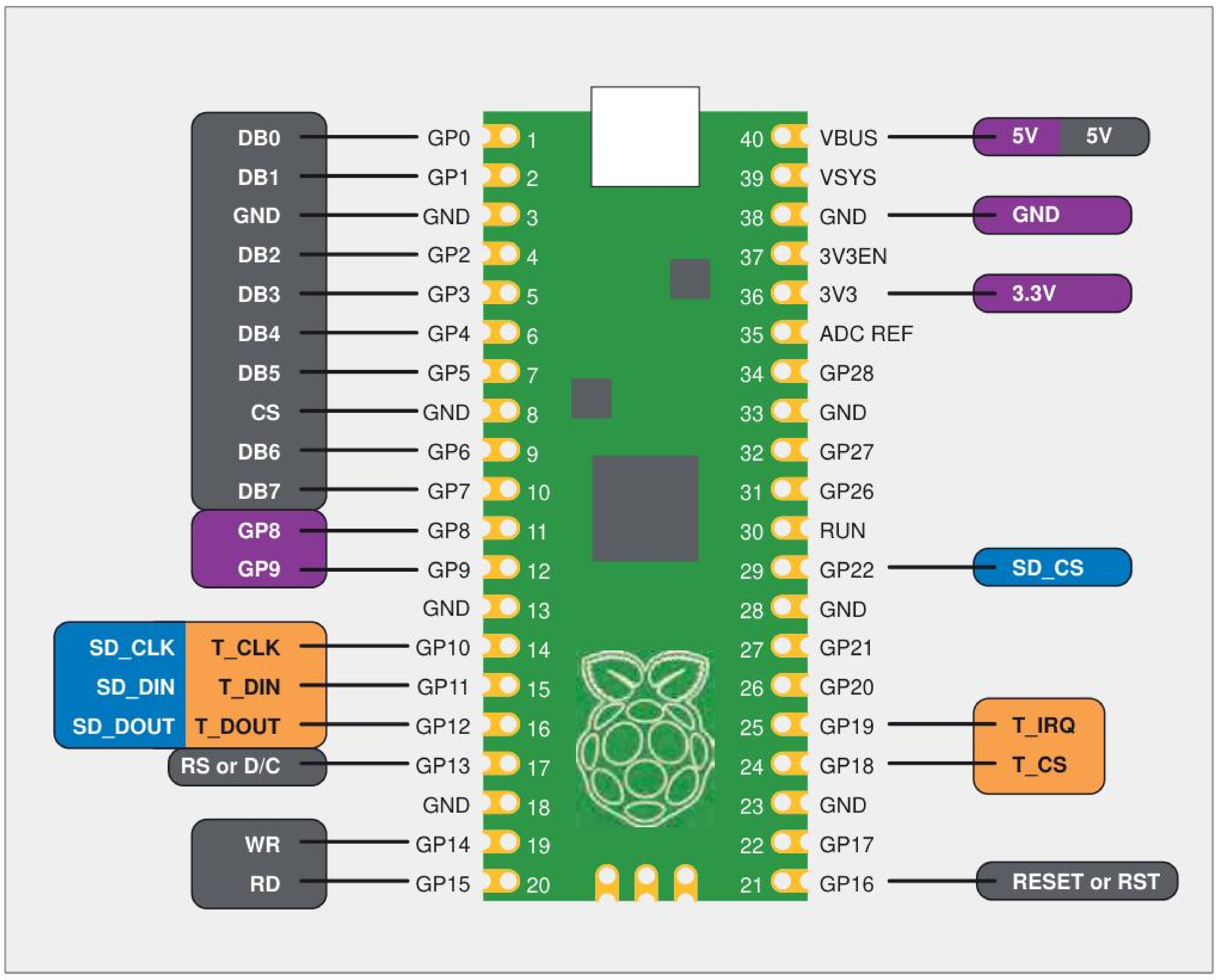

DB0
DB1
GND
DB2
DB3
DB4
DB5
CS
DB6
DB7
GP8
GP9
SD_CLK
T_CLK
SD_DIN
T_DIN
SD_DOUT
T_DOUT
RS or D/C
WR
RD
GP0 1
GP1 2
GND 3
GP2 4
GP3 5
GP4 6
GP5 7
GND 8
GP6 9
GP7 10
GP8 11
GP9 12
GND 13
GP10 14
GP11 15
GP12 16
GP13 17
GND 18
GP14 19
GP15 20
40 VBUS
39 VSYS
38 GND
37 3V3EN
36 3V3
35 ADC REF
34 GP28
33 GND
32 GP27
31 GP26
30 RUN
29 GP22
28 GND
27 GP21
26 GP20
25 GP19
24 GP18
23 GND
22 GP17
21 GP16
5V 5V
GND
3.3V
SD_CS
T_IRQ
T_CS
RESET or RST

Fig.4. The elements of the computer are attached to the PicoMite, as shown here. The TFT connection are shown in black, the touchscreen in orange, the SD card in blue and the keyboard level shifter in purple.

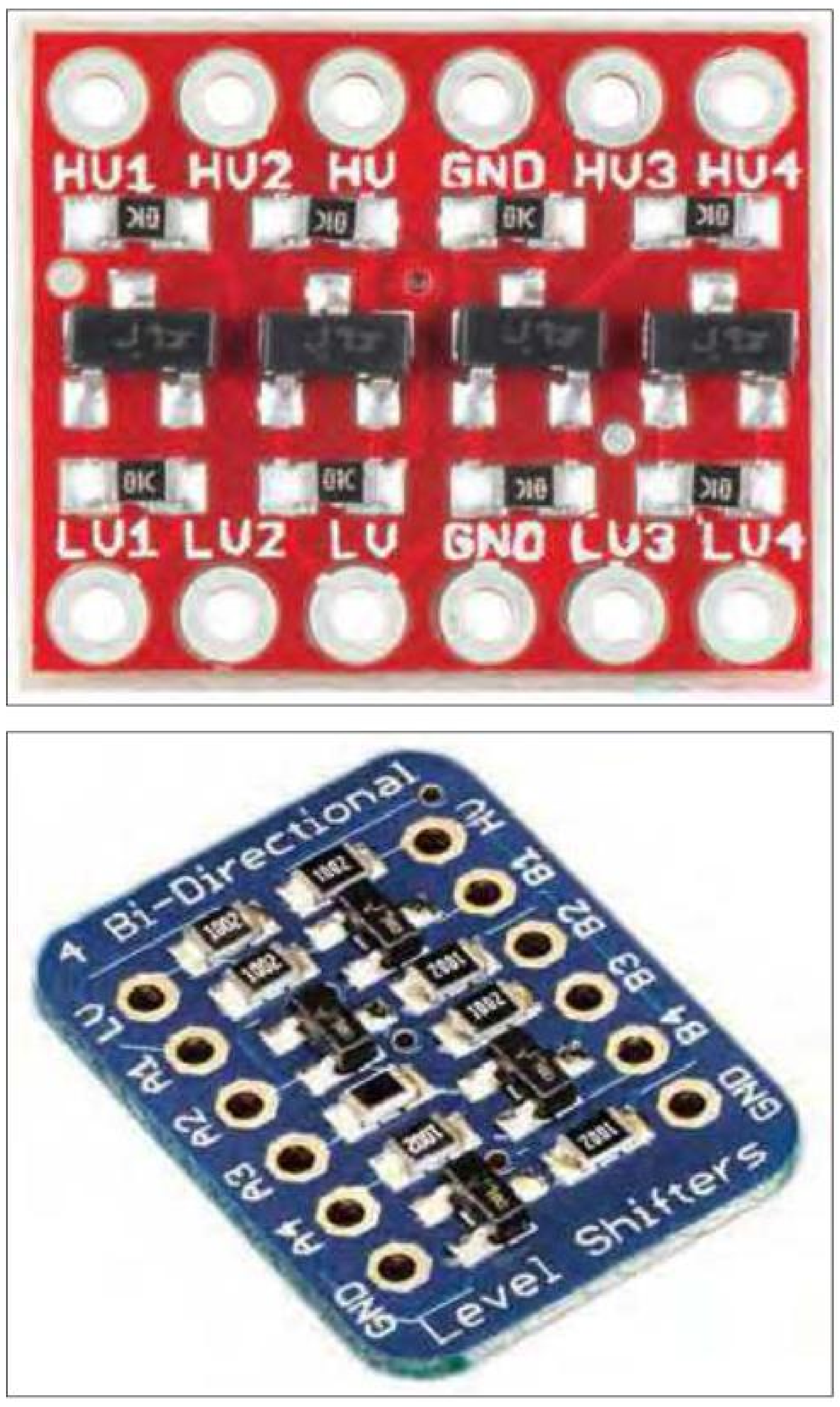

HU1 HU2 HU GND HV3 HU4
LU1 LU2 LV GND LV3 LV4
Bi-Directional
Level Shifters
HV
B1
B2
B3
B4
GND
LV
A1
A2
A3
A4
GND

Fig.5. Pre-built level shifters are available, but it is also possible to build your own very easily – see Fig.6.

`OPTION CPUSPEED 252000`
`OPTION LCDPANEL SSD1963_`***x***`,L` (replacing ***x*** with the appropriate parameter from the *User Manual*)

Once configured, you can test the screen by typing `GUI TEST LCDPANEL` – this should result in the usual test screen animation (animated coloured circles). If you don't see the test animation, then you'll need to check all the connections thoroughly.

Next, we need to ensure the screen is not upside-down. To do this we just need to write something to the screen by using the `TEXT` command. At the command prompt, simply type `TEXT 400,240,TIME$,CM,2,3` and check if the numbers displayed are the correct way round. If not, type `OPTION LCDPANEL DISABLE` followed by `OPTION LCDPANEL SSD1963_`***x***`,RL` (replacing ***x*** with the appropriate parameter from the *User Manual* as we did above). All we are doing here is using the 'reverse landscape' parameter in the `OPTION` configuration instead of 'landscape'.

Testing the Backlight

After you have successfully completed the above tests, it's time to test the backlight. Begin by typing something like `CLS RGB(blue)` to see a coloured screen, and then type `BACKLIGHT 50` and check that the display dims a little. If not, then check the jumper that controls the backlight and modify as highlighted above in the *Backlight control* section.

Continue by typing `BACKLIGHT 0` which should result in a totally dark screen, and then `BACKLIGHT 100` which will set the screen back to full brightness.

After all these tests have been completed successfully setting up the touchscreen comes next. (If you don't have the touchscreen option installed on the TFT module, then proceed directly to the *PS/2 keyboard* section below.)

Micromite code

There is no project code this month, but where applicable, code is available for download from the PE website.

Connecting the Touchscreen

The touchscreen is effectively an SPI device and requires five connections, as shown in orange in Fig.4. These comprise three SPI connections (T_CLK, T_DIN (MOSI), and T_DOUT (MISO)), and two control signals (T_CS, and T_IRQ). Now make these five connections and then configure the touchscreen by typing the following two lines:

```
OPTION SYSTEM SPI GP10,GP11,GP12
OPTION TOUCH GP18,GP19
```

Calibrating the touchscreen

Next, the touchscreen will need calibrating by using the command `GUI CALIBRATE`. Simply follow the onscreen instructions displayed on the TFT (ie, touch the four crosshairs in each corner in turn). If the touchscreen does not respond then there will be an error either in the five connections related to the touchscreen, or the parameters have been typed incorrectly. Use `OPTION LIST` to see the parameters set and use `OPTION TOUCH DISABLE` prior to correcting any mis-typed parameters.

Testing the touchscreen

To test the touchscreen, use the command `GUI TEST TOUCH` and use a plastic stylus (or equivalent) to draw on the screen. Pixels should appear at the point of contact; so using a fine tipped stylus means the accuracy can be better observed. Should the pixels appear offset to the point of contact, simply perform the calibration process again, taking care to touch the centres of each crosshair.

PS/2 keyboard

The PicoMite computer uses a PS/2 keyboard due to the simplicity of the PS/2 protocol (when compared to the USB protocol). Even though USB keyboards have flooded the market, it is still possible to purchase PS/2 keyboards online, especially through the likes of eBay. There is also a chance that you have a spare PS/2 keyboard lying around in a drawer somewhere.

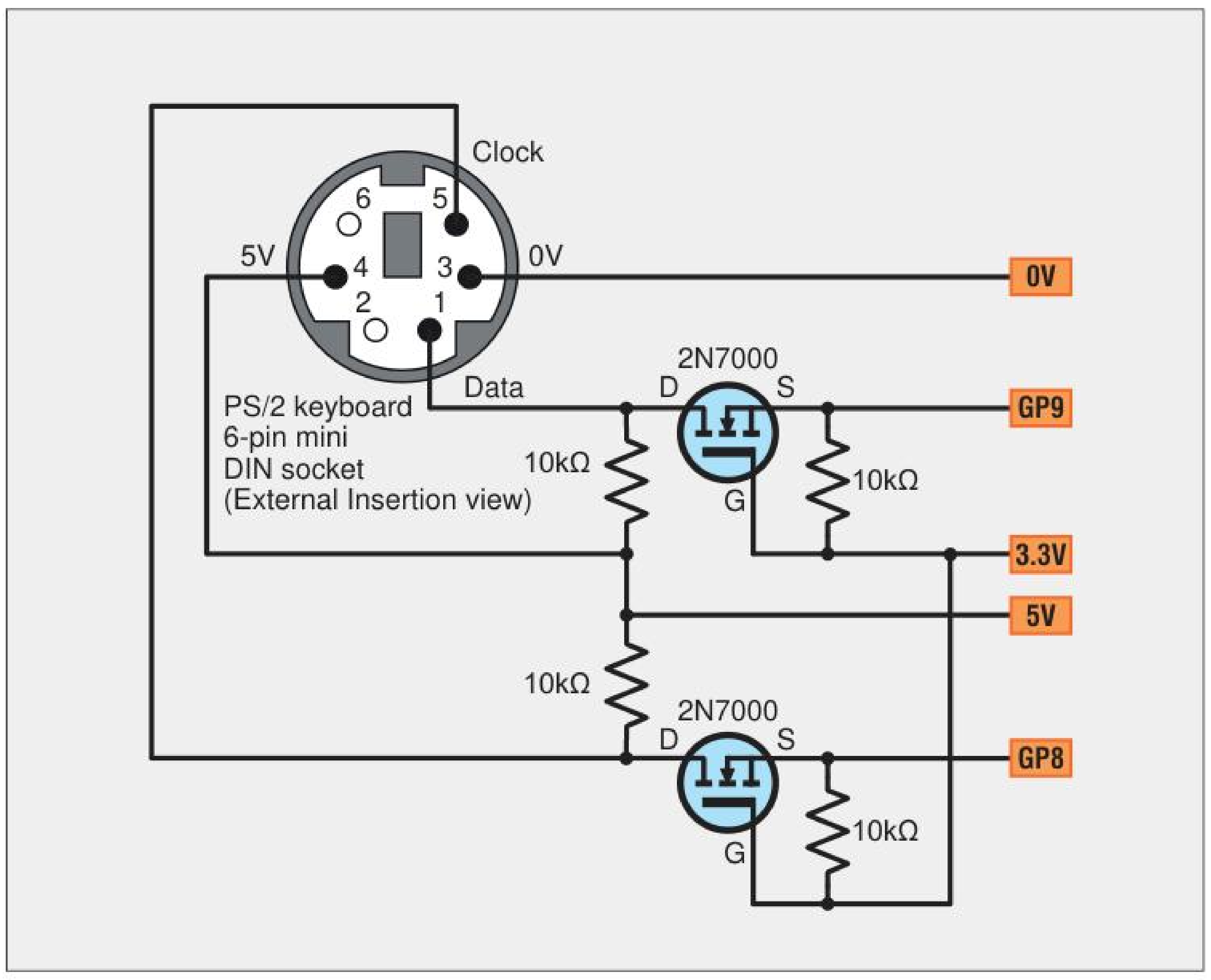


Fig.6. A simple level shifter for the PicoMite computer can be built with just four 10kΩ resistors and two N-Channel MOSFETs, as shown here.

One point to highlight here is that PS/2 keyboards are designed to operate at 5V, and this means the two signals (Clock and Data) coming out from the keyboard are at a 5V logic level.

However, the Pico module has a maximum rating of 3.6V on any input pin. If we connect the 5V keyboard directly to the PicoMite then it will result in permanent damage to the PicoMite's input pins (GP8 and GP9 in this case). Therefore, we must use a level-shifter circuit to bring the 5V signals down to a safe 3.3V, thus avoiding any damage to the PicoMite.

Level shifter

You can think of the level shifter as having an input side operating at 5V (which connects to the PS/2 keyboard), and an output side operating at 3.3V (which connects to the PicoMite – pins GP8 and GP9).

It is possible to buy a pre-built level-shifter module; two common examples are shown in Fig.5. Alternatively, you can build your own on a small piece of stripboard or Veroboard. All you need are four 10kΩ resistors, and two N-Channel MOSFETs (2N7000 or equivalent) – see Fig.6 for connection details. Either way, you will also need a PS/2 connector (effectively a 6-pin mini-DIN socket) into which you insert the PS/2 keyboard cable plug. The easiest method is to use a PS/2 breakout board (such as the one shown in Fig.7) which provides header pins to the four required keyboard connections (5V, GND, Clock, and Data). These header pins then connect directly to the level shifter.

If you build your own level shifter, then make the relevant connections to the PS/2 breakout board and the PicoMite as shown in Fig.6. However, if you're using a pre-built level shifter, then simply refer to Fig.8 instead.

Configuring the Keyboard

Once the keyboard circuit is connected, you will need to configure the keyboard (from your Terminal app) by typing the command `OPTION KEYBOARD UK`

Other keyboard layouts (ie, languages) are also supported – you simply replace the `UK` parameter with a different two-letter parameter. PS/2 Keyboard languages that are currently supported are: French (`FR`), German (`GR`), Belgium (`BE`), Italian (`IT`), Spanish (`SP`) and United States (`US`).

Configuring the console

Once the keyboard and display have been connected to the PicoMite, we can configure it to behave as a standalone computer. Before disconnecting the PicoMite from the PC/laptop, we need to enable the TFT to display the output that is normally sent to the Terminal app – in other words, enable 'the console'. This is done from your Terminal app by typing `OPTION LCDPANEL CONSOLE 2` (the parameter `2` is a reference to the default font; this can be changed to `1` (for smaller characters) or `3`, `4` or `5` (for larger characters)

Once the console is enabled, you will see the output that is normally displayed in the terminal app (ie, TeraTerm) shown on the TFT screen. Now press some random keys on the PS/2 keyboard and make sure they are displayed on the TFT (pressing Enter should then result in a 'Syntax Error'). However, if there is no response from the keyboard then check the keyboard circuit carefully (and ensure the keyboard is configured correctly using `OPTION LIST`).

Power supply

Once you have a working keyboard and console, you can remove the USB lead that currently connects the PicoMite to your laptop/PC. This will power everything down. Now connect a suitable 5V USB power supply directly to the PicoMite and you should see the MMBASIC welcome message appear on the TFT. From now on, anything you type on the keyboard will appear on the screen. If not, check that you have not accidentally dislodged a cable. Also, do ensure that your USB PSU can supply at least 300mA (most are now a minimum of 1A). If you have got to this point, then you are almost done – we just need to connect (and configure) the SD card socket.

SD card

An SD card is essentially an SPI device (just like the touchscreen). Only four connections are required to connect it to the PicoMite, as shown in blue in Fig.4. These comprise

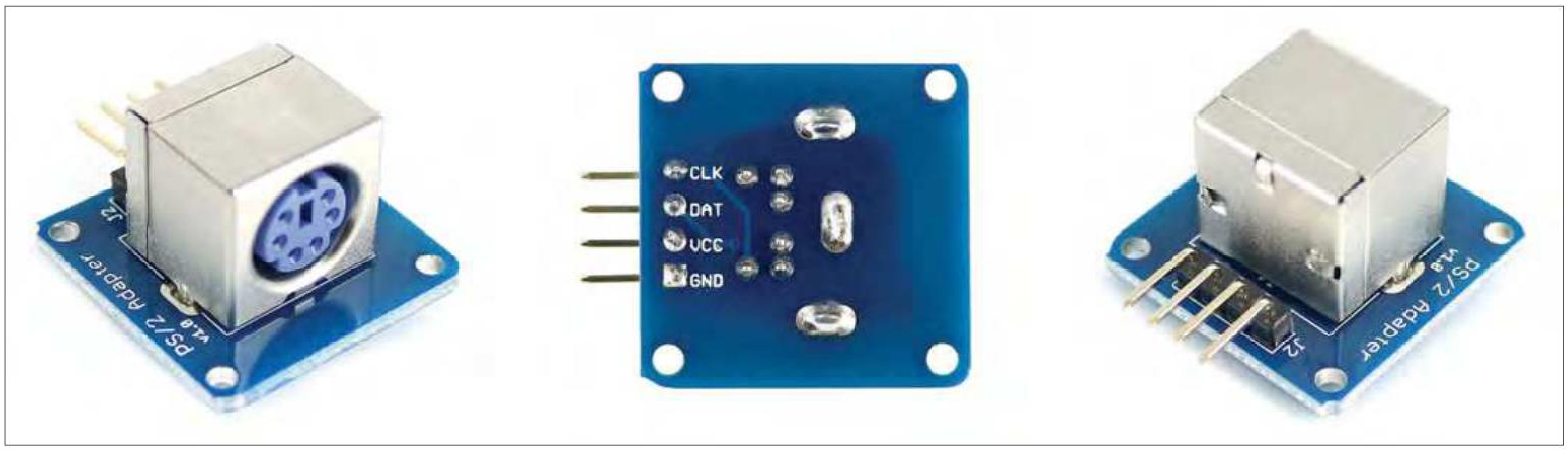


Fig.7. A PS/2 breakout board like this one makes it easy to connect the PS/2 keyboard to the level-shifter.

three SPI connections (SD_CLK, SD_DIN (MOSI), and SD_DOUT (MISO)), and one control signal (SD_CS). Now make these final four connections, and then configure the SD socket by typing `OPTION SDCARD GP22` on the PS/2 keyboard. Next, insert an SD card and type `FILES` which should display the contents of the SD card. If it fails to see the SD card, then check the four connections first, then check the `OPTION` parameters (with `OPTION LIST`) and finally check the SD card. Note that the SD card should ideally be 8GB, 16GB or 32GB. Other capacities may work, but all brands of these sizes tested so far seem to work without exception.

Summary

If you have successfully reached this point in assembling this project then you should now have a fully functioning standalone PicoMite computer. If so, you can now do lots of experimenting (either pure programming, and/or controlling other external hardware) without the need for an attached laptop or PC.

However, if you have struggled at any point, then just drop me an email with the relevant details and I will assist in getting you back on track!

Do please send photos of your PicoMite computer, including a brief description as to how you're using it. It is always nice to hear about your projects and experiences.

Questions? Please email Phil at:
contactus@micromite.org

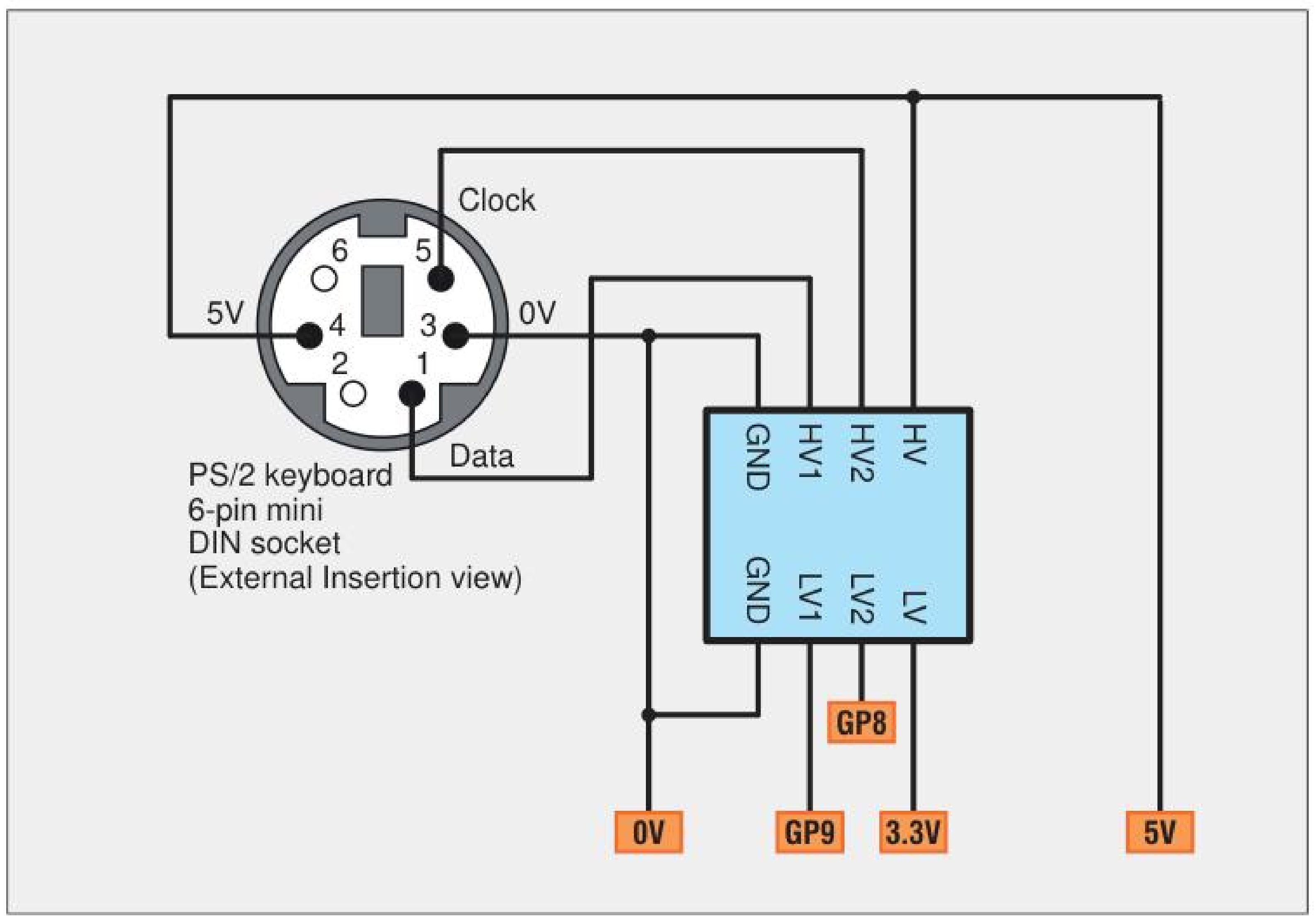


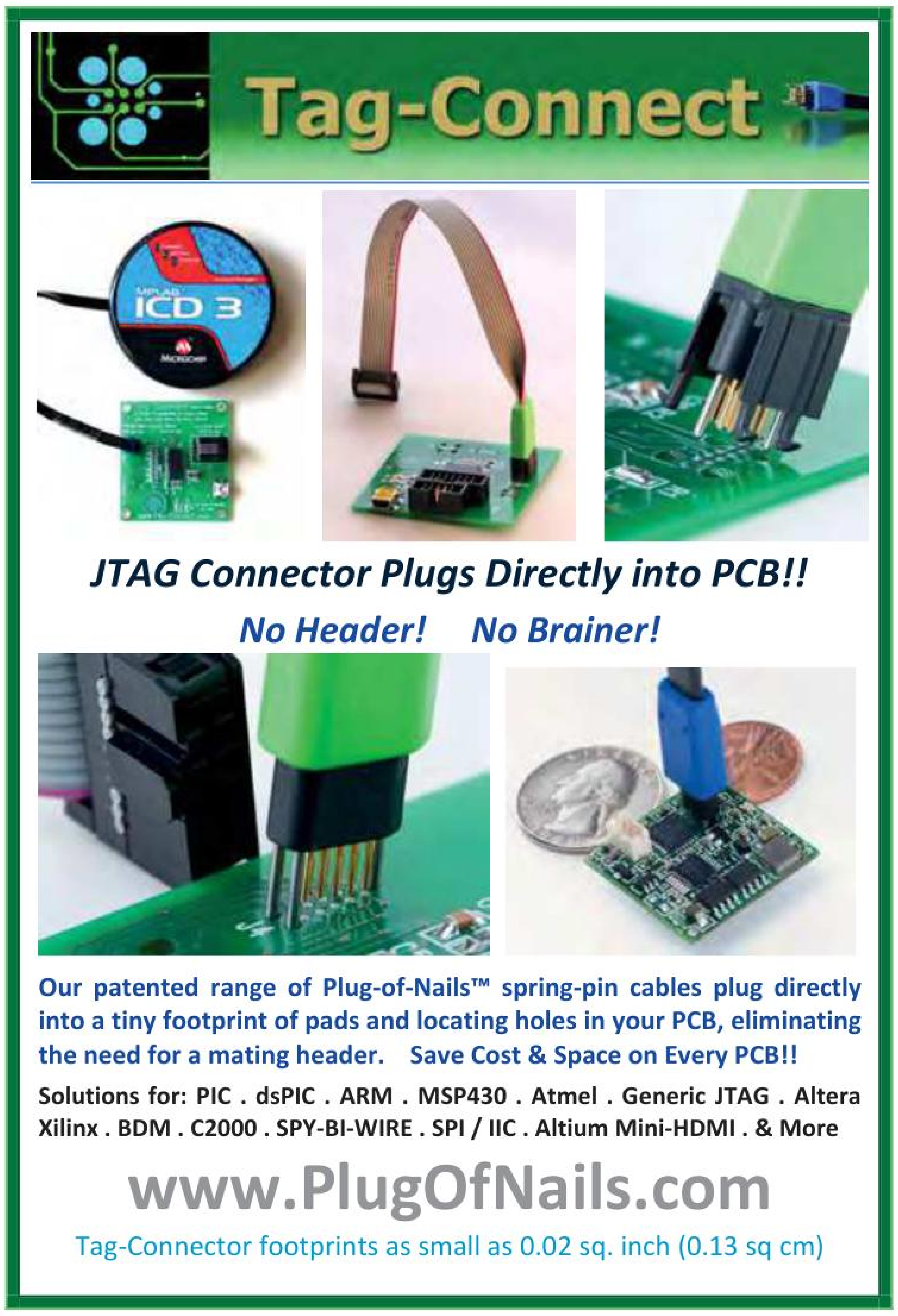
Fig.8. If using a pre-built level shifter, then connect it to the PicoMite and the PS/2 breakout board as shown here.

Next time

By the way, we have not forgotten about the fingerprint reader mentioned last month; we just had a slight mishap after attaching a slightly too higher voltage to it! Hopefully a replacement will arrive in the coming days, in which case we will discuss how to use it with the PicoMite.

However, if the world's mangled supply chains are unable to deliver a new fingerprint reader then we'll look at a super variation to the TFT PicoMite computer – one that we think you'll really like – a VGA version of a standalone computer.

Until then, stay safe, and do have FUN with your new PicoMite computer!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AUDIO OUT

By Jake Rothman

Transformers in audio – Part 4

Like many inductive parts, audio transformers are a little unusual and are often custom wound. So, in this month's *Audio Out* I will provide a comprehensive list of the most common parts that I've come across over 40 years, together with their specifications and application. Note that some companies listed no longer exist – such as Repanco – and the data is provided for historical reference and for when you are working on old equipment. However, most of the items in the tables below are available from the AO shop.

Before we go any further, here's a recap on all-important audio transformer function of converting from turns ratio (N) to impedance, and *vice versa*.

$N^2 = Z_p/Z_s$ or $N = \sqrt{(Z_p/Z_s)}$

For example, with a 10kΩ:3Ω transformer:

$N = \sqrt{(10{,}000/3)} = 58$

Therefore, the transformer has a ratio of 58:1

Going the other way:

Impedance $Z_p = N^2 \times Z_s$

So with a ratio of 58:1

$Z_p = (58^2) \times 3 = 3364 \times 3 = 10092\Omega$

Back to front

A transformer can usually be used 'backwards' with the secondary and primary windings swapped. The terms 'primary' and 'secondary' are merely designations and the fundamental transformer equations work both ways. For example, an LT700 makes an effective step-up transformer for a loudspeaker used as a microphone in an intercom.

I've noticed on some data sheets that the turns ratio and impedance don't agree. This could be because they are stating the optimum source and load impedances for flat response. Also, where there are dual secondaries, such as in the T/T3, 3.6:1+1, the quoted impedance may just refer to one secondary. There is also sometimes confusion over centre taps. An 8000Ω centre-tapped primary can also be described as 2000Ω + 2000Ω. This is because if two identical windings are connected in series then the DC resistance doubles, but the impedance quadruples. If two windings are connected in parallel the DC resistance is halved and the impedance remains the same. This is because the number of turns is effectively the same, but the cross-sectional area of the wire is doubled.

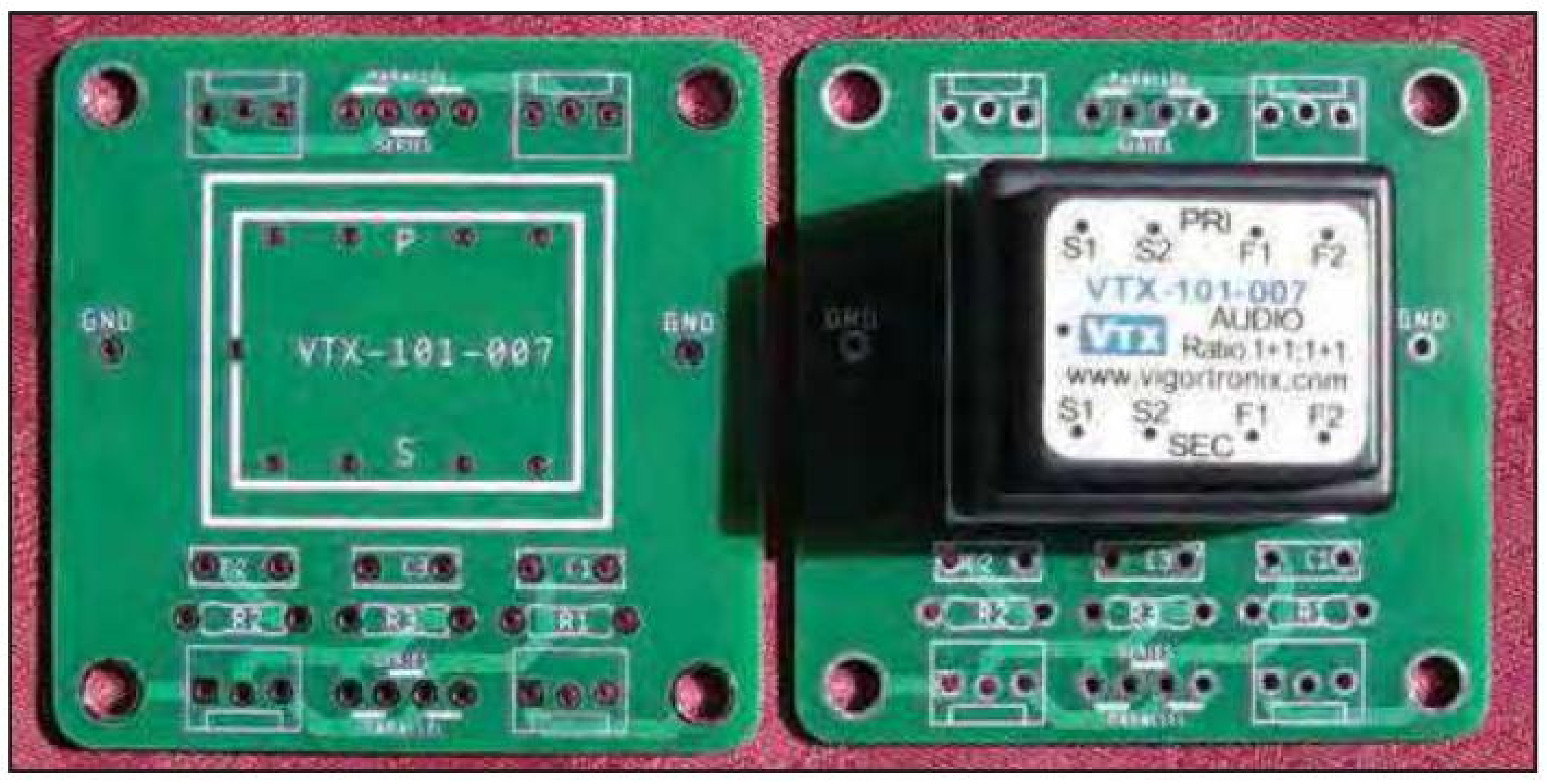

Fig.39. The Vigortronix/OEP transformer mounting boards. These allow series/parallel linking, Zobel networks and the use of Molex connectors.

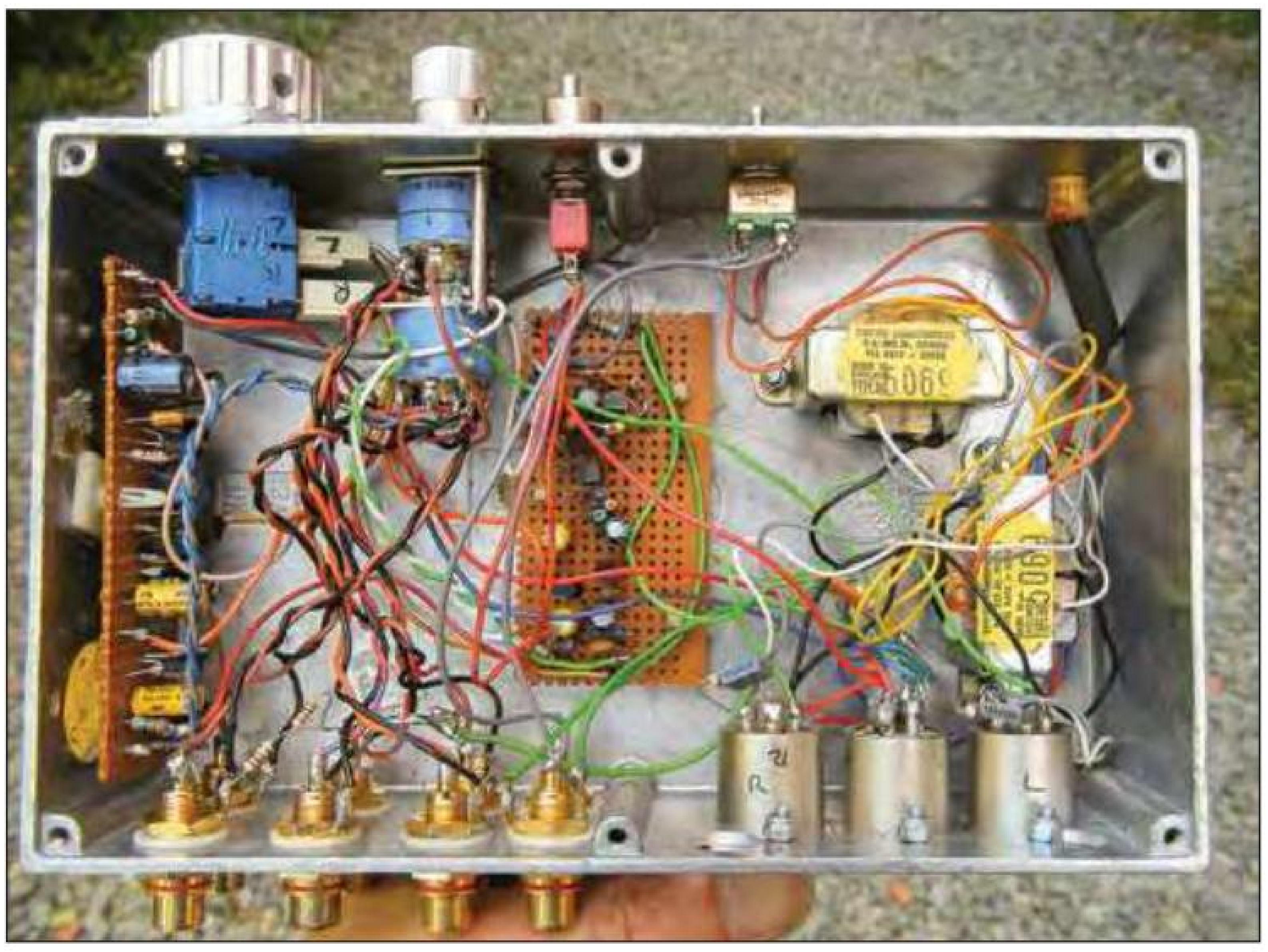

Fig.37. Studio monitor control unit with Sowter 5069 Mumetal/M6 output transformers. The Zobel network is 22nF and 1.5kΩ. This is the same transformer that we discussed in Fig.30 in *Part 2*.

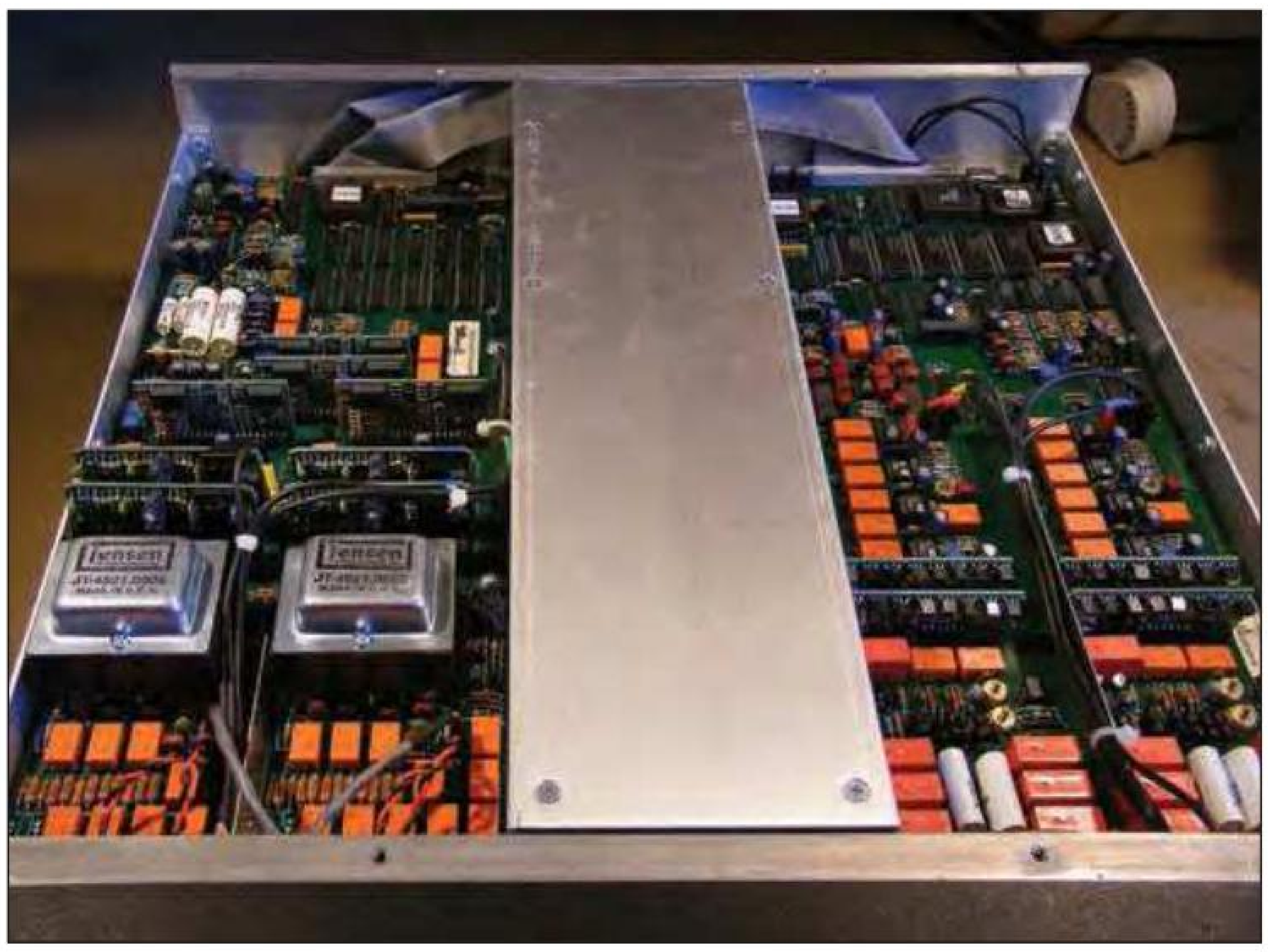

Fig.38. Custom-wound Jensen output transformers (lower left) in the Audio Precision SYS-2712 analyser. This transformer balanced output has the lowest distortion I've ever seen. It has to, since it is the system by which other amplifiers are measured.

Table 1: Cheap 'n' cheerful audio transformers (* – still in production)

Part Number	**Manufacturer**	**Application**	**Turns ratio**	**Impedance ratio**
LT700*	Eagle/generic	Push-pull output 200mW or class A in Ladybird book radio	20CT:1	1.2kΩ CT to 3Ω
LT44*	Eagle/generic	Push-pull driver (often used as high-value 5.8H to 9H inductor)	4.5:1CT	20k:1k CT
LT717	Eagle	Input for step-up. Bipolar transistor input	12:1	150kΩ:1kΩ
LT722	Eagle	Push-pull driver (Deacy amp)	1.4:1	2kΩ:1kΩ CT
LT726	Eagle Jaycar MM-2530	push-pull output 200mW	12.5CT:1 (3.2Ω) or 7.9CT:1 (8Ω)	500Ω CT to 3.2Ω or 8Ω
LT730	Eagle	Push-pull output 500mW 500Ω CT:3.2Ω + 8Ω	12.5CT:1 or 7.9CT:1 (8Ω)	500Ω CT:3.2Ω or 8Ω
T/T1, E187A 217-624*	Repanco/OEP/RS Jaycar MM-2532	Push-Pull driver 1mA DC in pri 800Ω:800Ω CT 2mW	1:1CT	800Ω:800Ω CT
T/T2	Repanco	Push-pull output 200mW low voltage 4.5V/6V OC72 amp	6.6CT:1	130Ω CT : 3Ω
T/T3 or E187B 217-646*	Repanco/OEP/RS	Dual-secondary driver 5mW small Ravensbrook amp	3.6:1+1	3kΩ : 250Ω + 250Ω
T/T4	Repanco	Single-ended speaker output 50mW 20mA DC	9:1	243Ω : 3Ω
T/T6	Repanco	Push-pull driver	2.8:1 CT	7.8kΩ: kΩ
T/T7	Repanco	Push-pull output 1W 9V 2x OC81	9.2CT:1	250Ω:3Ω
T/T12	Repanco	Class A 3W car radio output 2.9:1 400mA DC gapped core.	2.9:1	28Ω:3Ω
T/T23	Repanco	10W push-pull driver OC25 (80mA Ic)	2:1CT	
T/T24	Repanco	10W push-pull OC25 output Could possibly replace output transformer in Mullard 5W class-A PT1 transformer with worse bass. (Primary inductance 30mH, not 1H)	1.35+1.35:1+1	22Ω CT:15Ω sec windings in series 3Ω when in parallel
X7920	Greenweld	Interstage, collector load to base I/P	4.5:1	6kΩ:300Ω
GR51135	Gardeners	Balanced low impedance OP	1.35+1.35:1+1	22Ω CT:15Ω sec windings in series 3Ω when in parallel
PE Vocoder output	1:1	150Ω:150Ω	4.5:1	6kΩ:300Ω
250P*	Triad Magnetics (distributed by Mouser)	Tapped push-pull split output (suitable for low power Ravensbourne style Fig.14a)	2:1+1	1000Ω CT:250Ω+250Ω
42TU048-RC*	Xicon (via Mouser)	1W push-pull output useful for low-voltage outputs.	2.45:1 (8Ω)	48Ω CT:3.2 or 8Ω
42TU120-RC*	Xicon	1W push-pull output (Bush TR130 radio replacement).	3.9:1 (8Ω)	120Ω CT:3.2 or 8Ω
42TU200-RC*	Xicon (Mouser)	1W push-pull output (Deacy amp)	5:1 (8Ω)	200Ω CT:3.2 or 8Ω
42TU400-RC*	Xicon (Mouser)	1W push-pull output	7.9:1 (8Ω)	500Ω CT:3.2 or 8Ω
42TU003-RC*	Xicon (Mouser)	1W push-pull output op amp to speaker output	12.2:1 (8Ω)	1.2kΩ CT:3.2 or 8Ω
42TU400-RC*	Xicon (Mouser)	1W push-pull output	7.9:1 (8Ω)	500Ω CT:3.2 or 8Ω
42TU003-RC*	Xicon (Mouser)	1W push-pull output op amp to speaker output	12.2:1 (8Ω)	1.2kΩ CT:3.2 or 8Ω

The Audio Out guide to audio transformers

Our first list (Table 1) is for old transformer designs descended from the germanium transistor era (1954 to 1978). They were originally used for transistor radios and other consumer audio products. Note that a star (*) indicates the transformer is still being made.

Next, (Table 2) we have medium-priced audio transformers from companies such as Gardeners, Hammond, Sescom, Triad and Vigortonix. These are parts suitable for standard Hi-Fi and studio equipment; with optimised circuitry they can give excellent results.

Belclere, OEP (Oxford Electrical Products), STC/ESD and Vigortronix make a range of generic audio transformers, all with different part numbers for the same component (see the VTX-A series in Table 2). For the Steve Dove circuit in Fig.20 (*Part 2*) and Fig.25 (*Part 3*) you can use the Vigotronix VTX-101-003, Belclare/OEP A 262 A3E, RS 210-6426 or STC/ESD 66122X, which are all equivalent. The windings should be connected in series if phantom power (connected to the junction centre tap) is to be used and in parallel for moving-coil microphones. (However, for both configurations the turns ratio remains the same.) Vigortronix are the lowest-cost supplier of these components. Note that Vigortronix also make bespoke 'special' inductive components, including mains toroidal transformers.

Last, but not least, we turn to high-end audio transformers in Table 3. CineMag, Audionote, Gardeners, Jensen, Sowter, Partridge, Lundahl, Stevens & Billington and the BBC make the best transformers. The Audionote transformers even use silver wire for the 'cost-no-object Hi-Fi designer'; although, from a physics perspective I'm not convinced. However, if you are a single-ended triode amplifier enthusiast, they are the bee's knees. One important characteristic of expensive transformers is that they don't generally need specialised drive circuitry to give good results.

In professional audio gear the audio transformers are often the most expensive components, even more expensive than the toroidal mains transformer. They are worth it to many users/designers because they sound good, are totally reliable and it's the only way to get fully effective isolation from extraneous noise.

They are expensive because they are a hand-made niche component. If you look at the CiniMag 'how it's made video' (**https://youtu.be/TqOSfW5tqBA**) you will see lots of people doing skilled manual jobs with wires and sticky tape. Even laminations seem to be hand inserted one by one. It was the same when I visited ICW Capacitors recently, who

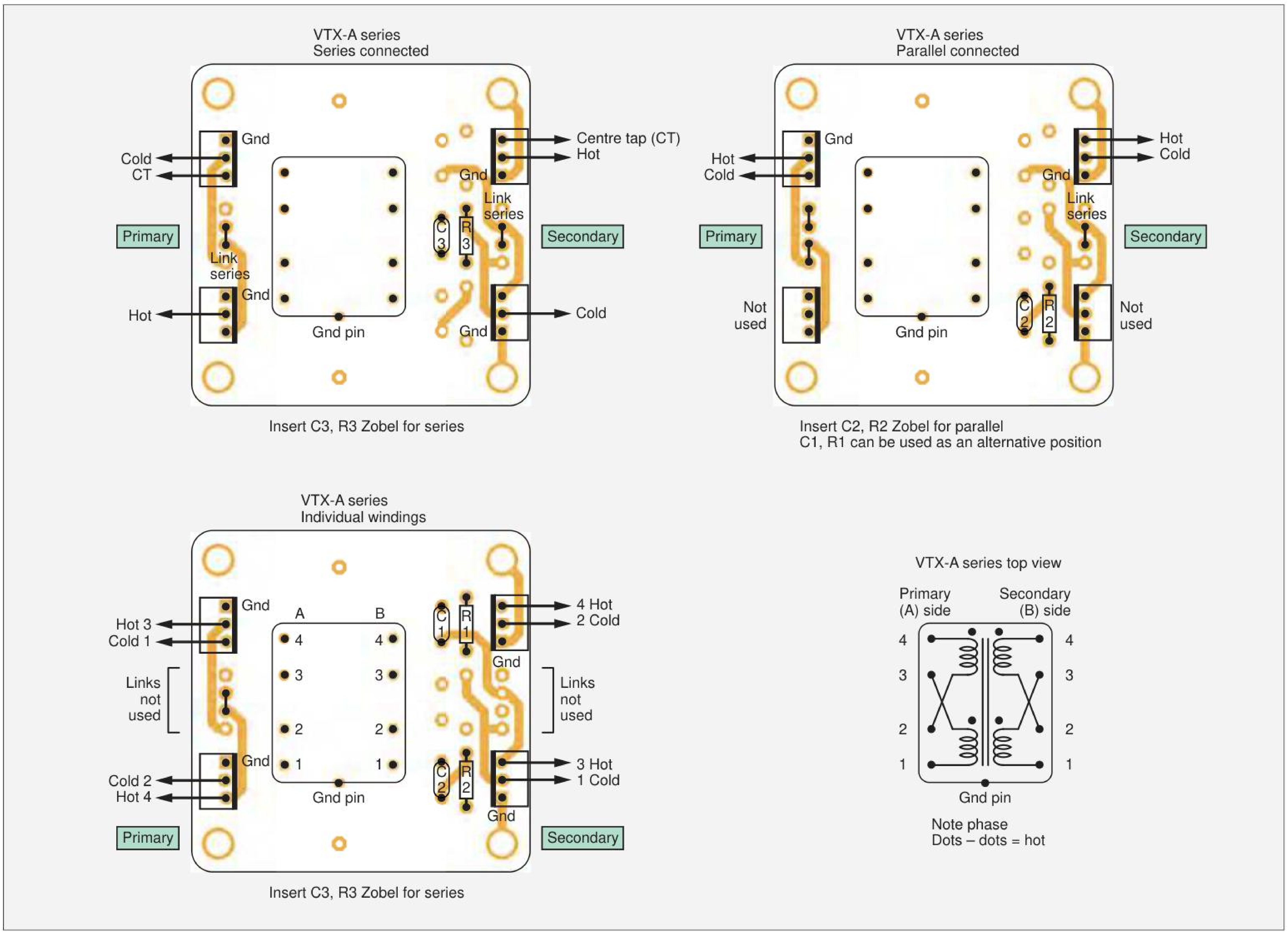
VTX-A series
Series connected
Gnd
Cold
CT
Centre tap (CT)
Hot
Gnd
Link
series
C3
R3
Primary
Secondary
Link
series
Gnd
Hot
Gnd pin
Gnd
Cold
Insert C3, R3 Zobel for series
VTX-A series
Parallel connected
Gnd
Hot
Cold
Hot
Cold
Gnd
Link
series
Primary
Secondary
Not
used
C2
R2
Not
used
Gnd pin
Insert C2, R2 Zobel for parallel
C1, R1 can be used as an alternative position
VTX-A series
Individual windings
Gnd
A
B
C1
R1
4 Hot
2 Cold
Hot 3
Cold 1
4
4
Gnd
3
3
Links
not
used
Links
not
used
2
2
Gnd
1
1
C2
R2
3 Hot
1 Cold
Cold 2
Hot 4
Gnd pin
Gnd
Primary
Secondary
Insert C3, R3 Zobel for series
VTX-A series top view
Primary
(A) side
Secondary
(B) side
4
3
2
1
4
3
2
1
Gnd pin
Note phase
Dots – dots = hot

Fig.40. Variations of the transformer-mounting boards. Note Zobel RC values are for high impedance loading (>20kΩ) and a signal generator source impedance of 50Ω.

make special capacitors for KEF speaker crossovers.

Sowter transformers are the most cost-effective of the top-quality units. (A couple of Sowters 5069 output transformers are shown in the studio monitor control unit in Fig.37.) Indeed, it was Dr GAV Sowter who did the main research on nickel-based core audio transformers in his 1945 London University PhD thesis. His seminal paper in the October 1987 issue of *JAES* (*Journal of the Audio Engineering Society*) is also well worth reading and this can be found on the Sowter website: **https://www.sowter.co.uk/pdf/GAVS.pdf**

Table 2: Medium-price audio transformers

Part Number	Manufacturer	Application	Turns ratio	Impedance ratio
VTX-101-001* A262A1E 88-2100	Vigortronix Belclere RS	Low impedance speaker or headphone output A series	6.3+6.3:1+1	150Ω+150Ω:3.75Ω+3.75Ω Note in series this would be 600Ω CT:15Ω CT
VTX-101-002* A262A2E 88-2102 66120D	Vigortronix OEP/ Belclere RS ESD	Interstage A series	1+1:2+2	150Ω+150Ω:600Ω+600Ω
VTX-101-003* A262A3E/EN6423 88-2104	Vigortronix OEP/ Belclere RS	Microphone input A series	1+1:6.45+6.45	Series 600Ω CT: 25kΩ Parallel 150Ω: 6.45kΩ
VTX-101-006* A262A6E 88-2106	Vigortronix OEP/ Belclere RS	Balanced line output A series	1+1:1+1	150Ω+150Ω:150Ω+150Ω In series 600 ohm
VTX-101-007* A262A7E 88-2108	Vigortronix OEP/ Belclere RS	Higher Z balanced line output 6V_{pk-pk} at 30Hz A series	1+1:1+1	600Ω+600Ω:600Ω+600Ω In series 2.4kΩ
VTX-101-3001* Z3001	Vigortronix OEP	Balanced line output PE Mic amp 10.6V_{pk-pk} at 30Hz	1:1	600Ω:600Ω
VTX-101-3002*	Vigortronix	Balanced line output High level 37V_{pk-pk} at 30Hz SiFe core	1:1+1	600Ω:600Ω+600Ω
76825D8380MO1	Generic/surplus	Mumetal modem transformer 300Hz to 20k used for active crossover tweeter output.	1:1	600Ω:600Ω
MI-81	Sescom	Line out distribution 4 outputs.	1+1:1+1+1+1	600Ω/150Ω

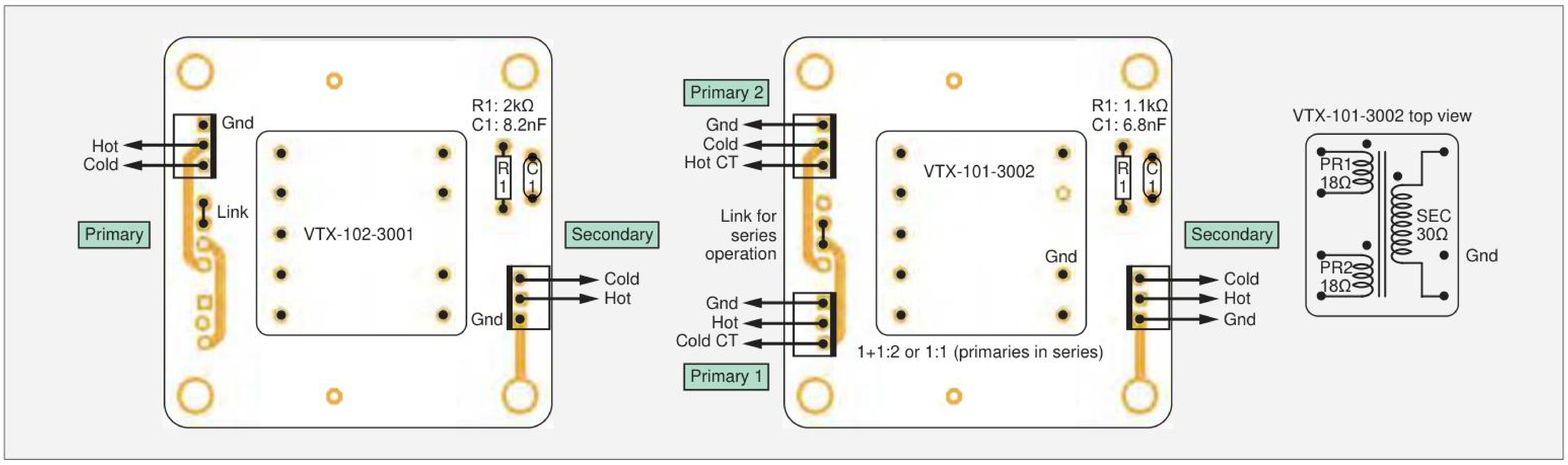
Hot
Cold
Gnd
Link
Primary
VTX-102-3001
R1: 2kΩ
C1: 8.2nF
R1
C1
Secondary
Cold
Hot
Gnd
Primary 2
Gnd
Cold
Hot CT
Link for series operation
Gnd
Hot
Cold CT
Primary 1
VTX-101-3002
Gnd
1+1:2 or 1:1 (primaries in series)
R1: 1.1kΩ
C1: 6.8nF
Secondary
Cold
Hot
Gnd
VTX-101-3002 top view
PR1 18Ω
PR2 18Ω
SEC 30Ω
Gnd

Fig.43. Dual-outline PCB for VTX-102-3001 and VTX-101-3002 output transformers. Note: the 6.8nF Zobel value is for a 50Ω source.

Jensen then took this further by making arguably the best audio transformers. I have only seen two in my whole career, the output transformers in the Audio Precision distortion analyser shown in Fig.38. In conjunction with a negative resistance driver amplifier, they give a distortion of less than 0.0002% over the full audio bandwidth. Jensen's JE-11BMCF output transformer is similar and has a THD of 0.002% with zero source resistance at up to +26dBu (15.46V rms or 43$V_{pk\text{-}pk}$). It should approach Audio Precision levels with the right amplifier, but how would I test it? Expect to pay well over £140 for one. Jensen have become so adept at balancing the capacitances and resistances of their transformers that most don't even need Zobel networks. The upper response roll-off approximates to a Bessel curve which gives superior group delay, thereby benefiting transient response.

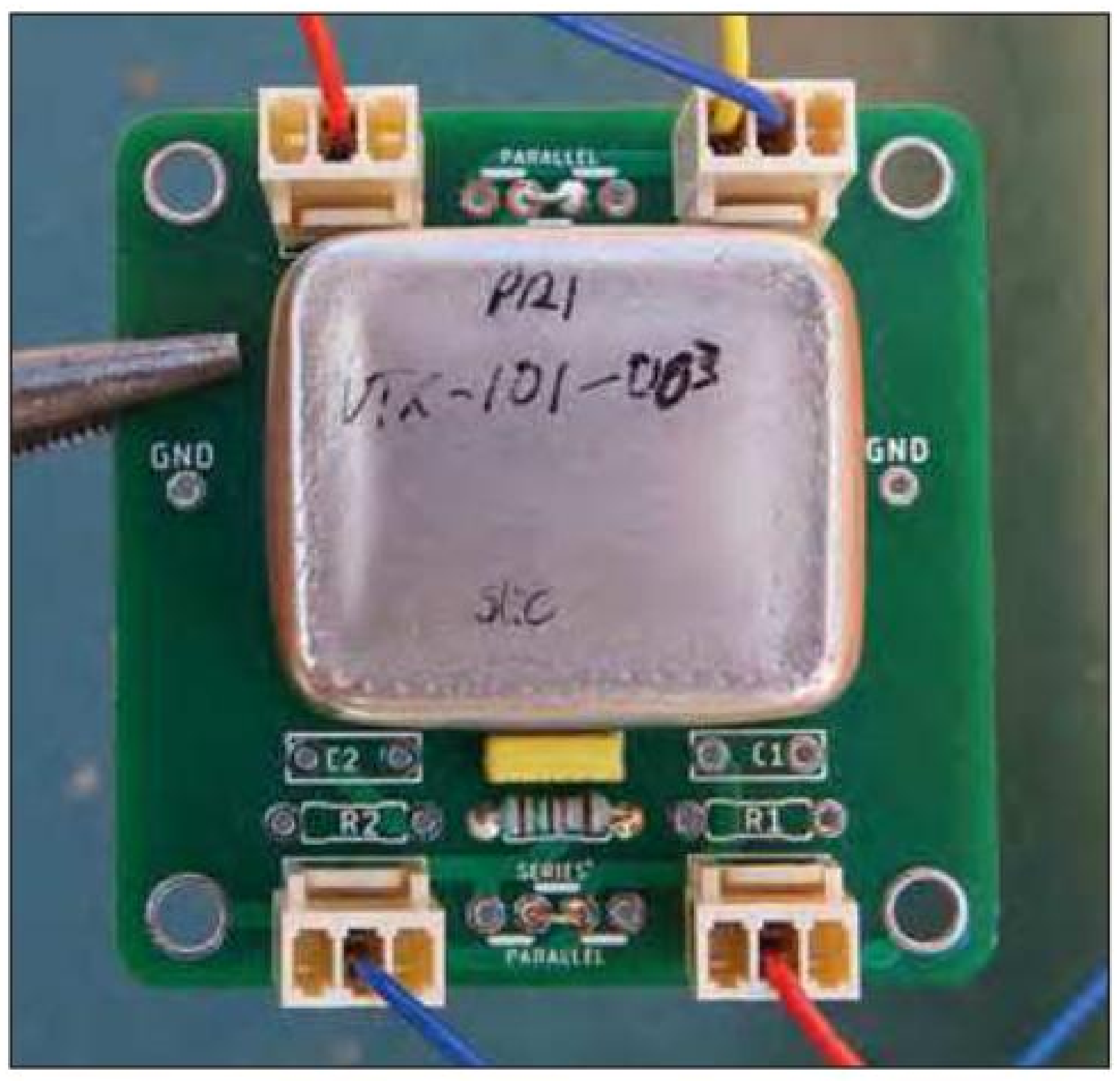
PR1
VTX-101-003
SEC
PARALLEL
GND
GND
C2
C1
R2
R1
SERIES
PARALLEL

Fig.41. VTX-101-003 Microphone transformer with screening can showing series-connected windings. The Zobel values are 680pF and 15kΩ. The VTX-101-007 with secondaries in series is wired the same way with a Zobel of 13nF and 1.8kΩ.

Let's get building

High-quality audio transformers are much heavier than most components and mounting them requires extra care. Veroboard and other Paxolin boards just aren't strong enough. Small 'Lo-Fi' transformers from Eagle and Xicon are fine mounted on stripboard. Big audio transformers can weigh over 200g and often need to be bolted down, especially on PCBs. Today's fibre-glass PCBs are much stronger than stripboard, especially if they have plated-through holes. For this reason, I've had a couple of PCBs designed by Mike Grindle to mount some commonly available transformers from Vigortronix and OEP, which are used in the bulk of my designs. These are both available from the *PE PCB Service* – November 2022 section.

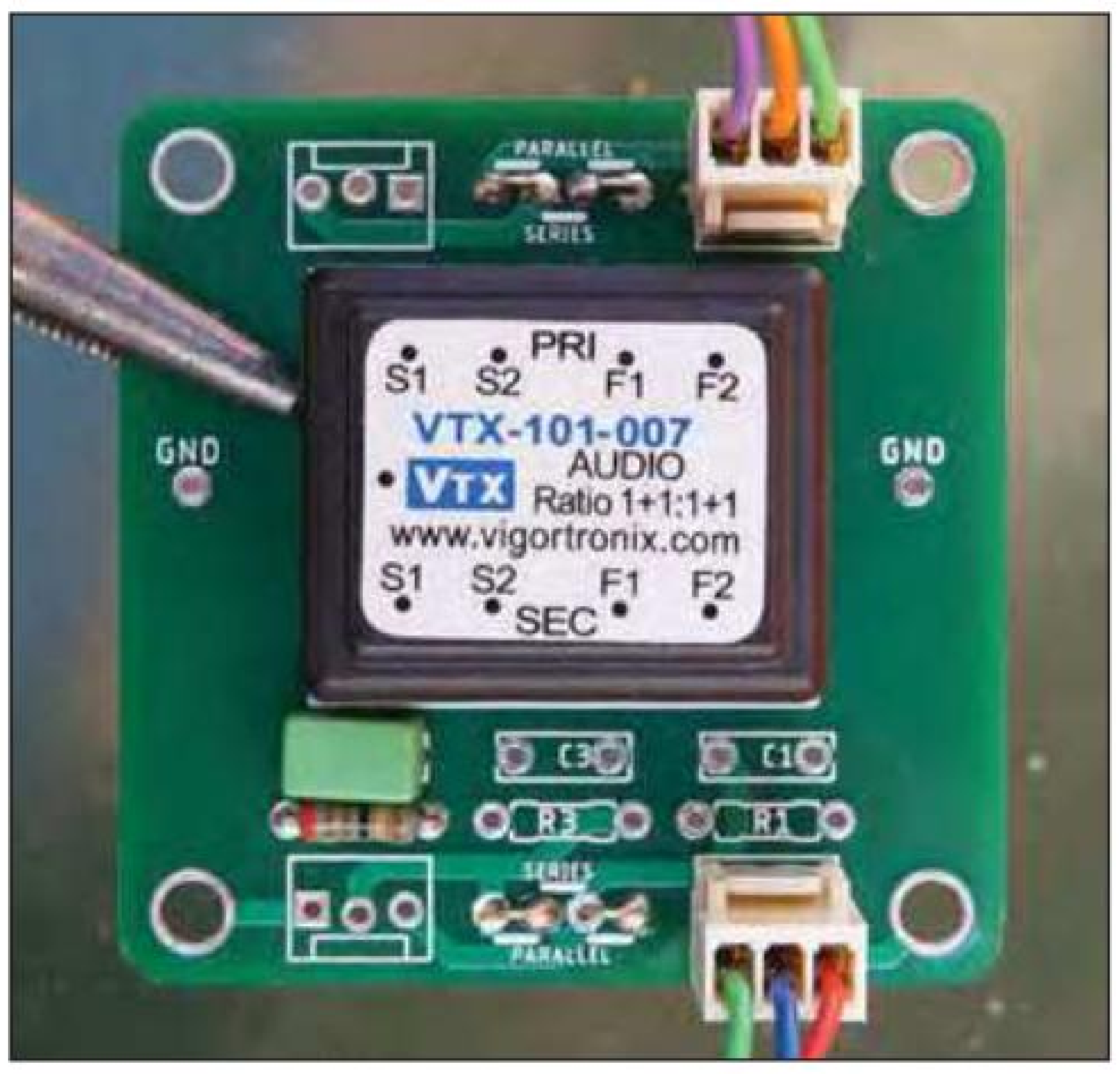
PARALLEL
SERIES
PRI
S1 S2 F1 F2
VTX-101-007
AUDIO
VTX
Ratio 1+1:1+1
www.vigortronix.com
S1 S2 F1 F2
SEC
GND
GND
C3
C1
R3
R1
SERIES
PARALLEL

Fig.42. Line-output board with parallel-connected VTX-101-007 transformer. The Zobel network is 1.3kΩ and 6.8nF.

The first board is designed for the standard VTX-A range and has provision for wiring both the dual primaries and secondaries in series or parallel using links. The earthing is via the mounting holes, with the earth also available on the Molex connectors for cable screening. There is also provision for Zobel networks. There can be two separate networks on individual secondaries (for phase splitters) or a single one. This is used when the two secondaries are combined as one winding, either in series or parallel on the boards, as shown in Fig.39. The overlays are shown in Fig.40. An assembled microphone input board is shown in Fig.41. A line output board for the VTX-101-007 is shown in Fig.42.

Table 3: High-end and expensive

Part Number	Manufacturer	Application	Turns ratio	Impedance ratio
LL/76MPC	BBC	Mumetal low-level, 6$V_{pk\text{-}pk}$ at 30Hz	1:1	600Ω:600Ω
LL/942PU	BBC	Mumetal high level +20dBu	1:1	600Ω:600Ω
CMOQ-2 HiNi*	CineMag	Mumetal high level +22dBu	1:1	600Ω:600Ω
JE-11BMCF*	Jensen	Mumetal high level +26dBu	1:1	600Ω:600Ω
JE-16A*	Jensen	Mic to 990 discrete op amp	1:2	150Ω :600Ω
LL 1530*	Lundahl	Mumetal Mic to 5534 IC	1+1:3.5+3.5	600Ω:7.35kΩ in series
3785*	Sowter	High level input isolation transformer +26dBu at 50Hz	1:1	10k:10k
5069	Sowter	Mumetal/M6 combination core high level +25dBu at 50Hz	1:1	600Ω:600Ω
Neve LO1166 Sowter 1717 is the replacement*	St Ives Windings Sowter (both now Carnhill)	SiFe M6 core high level gapped core for BA283 amp 85mA DC +26dBu at 50Hz	1:1.67 windings in series	150:600Ω windings in series

Note: Sowter and OEP have been taken over by Carnhill Transformers (**https://carnhill.co.uk**).

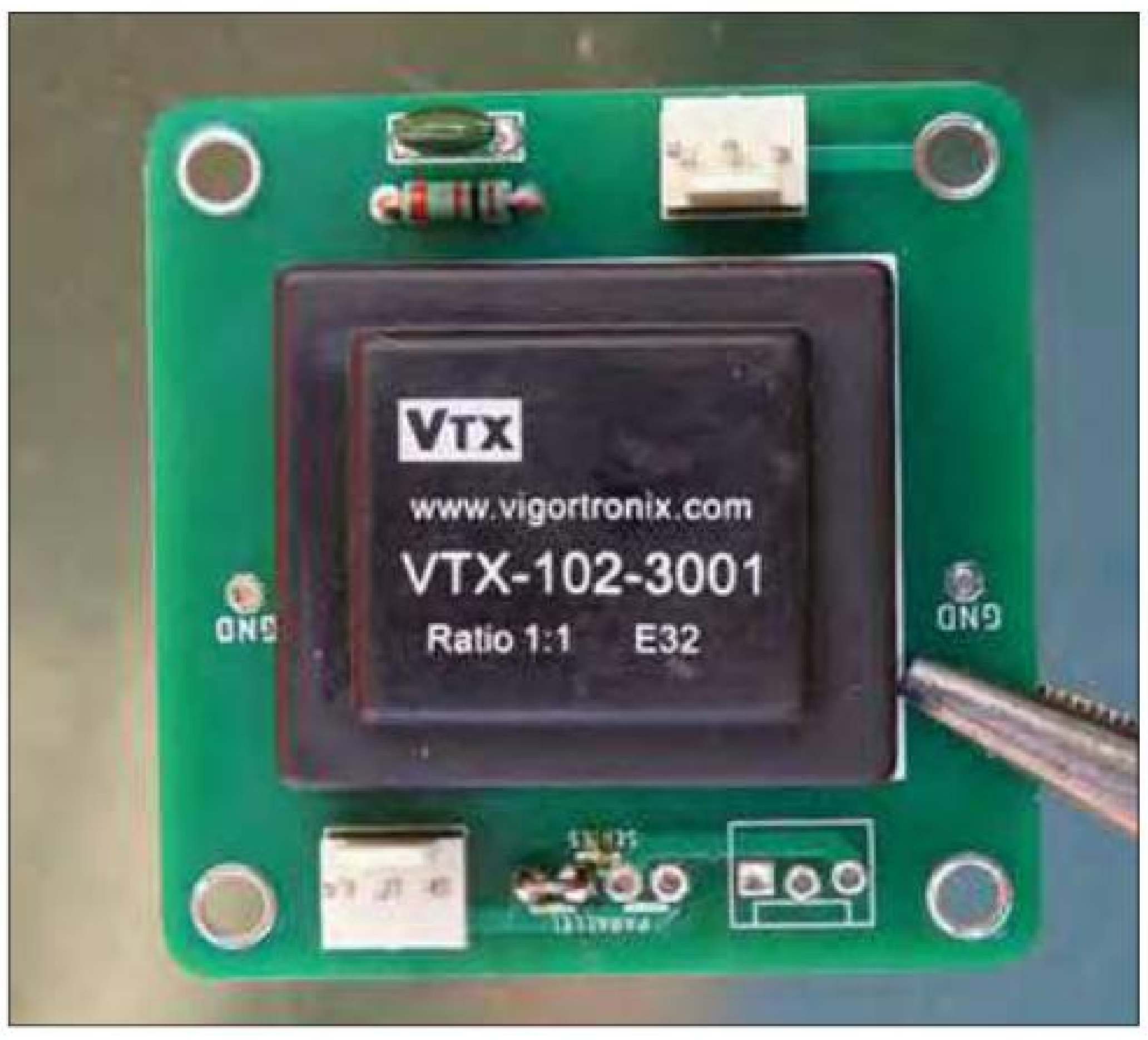
VTX
www.vigortronix.com
VTX-102-3001
Ratio 1:1 E32
GND
GND

Fig.44. 3001 assembly – the Zobel network is 2kΩ and 8.2nF.

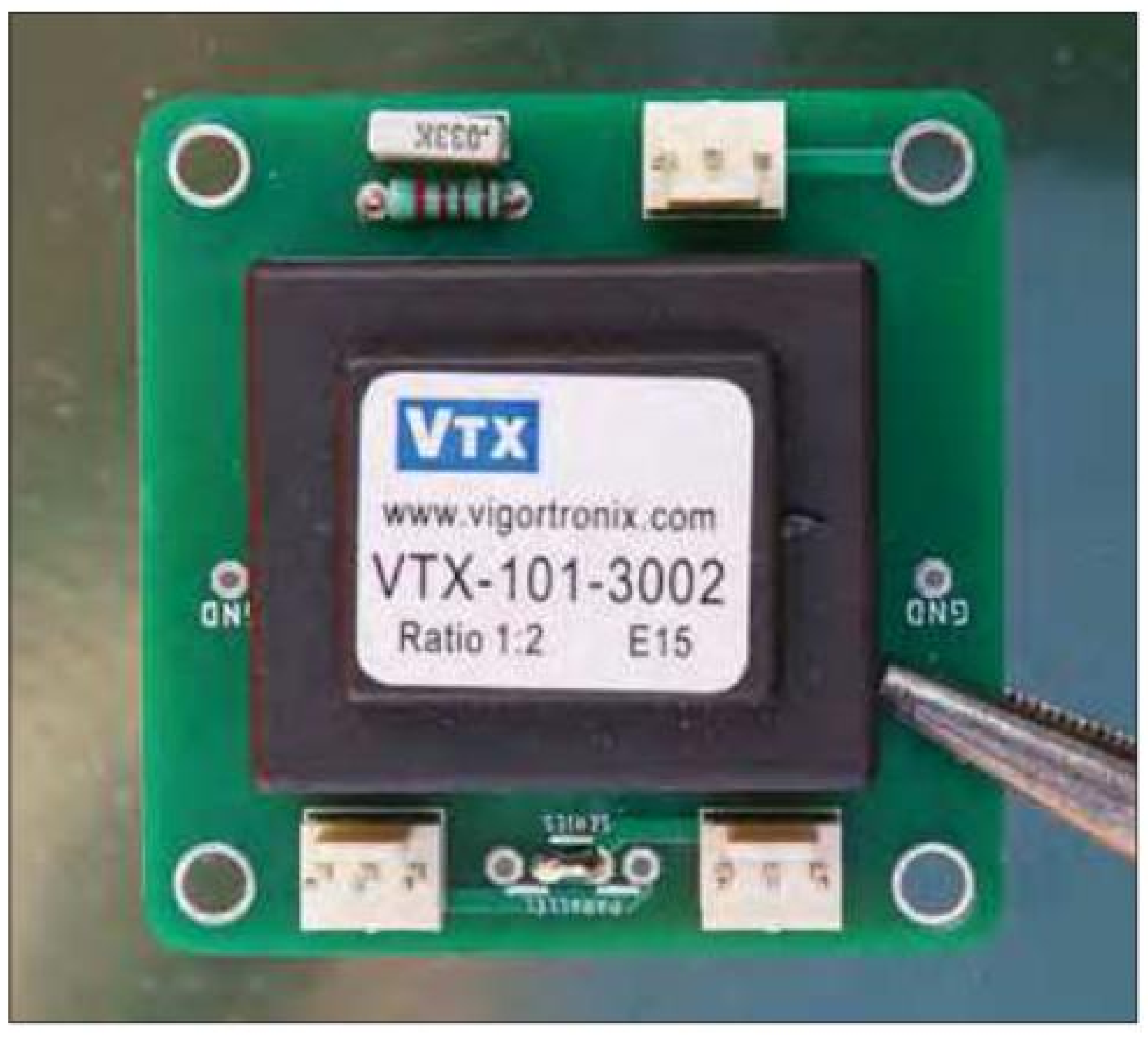
VTX
www.vigortronix.com
VTX-101-3002
Ratio 1:2 E15
GND
GND

Fig.45. 3002 version. Here, the primaries are connected in series giving a 1:1 ratio.

Fig.48. Hebden Sound condenser microphone. Like most studio microphones it contains small audio transformers.

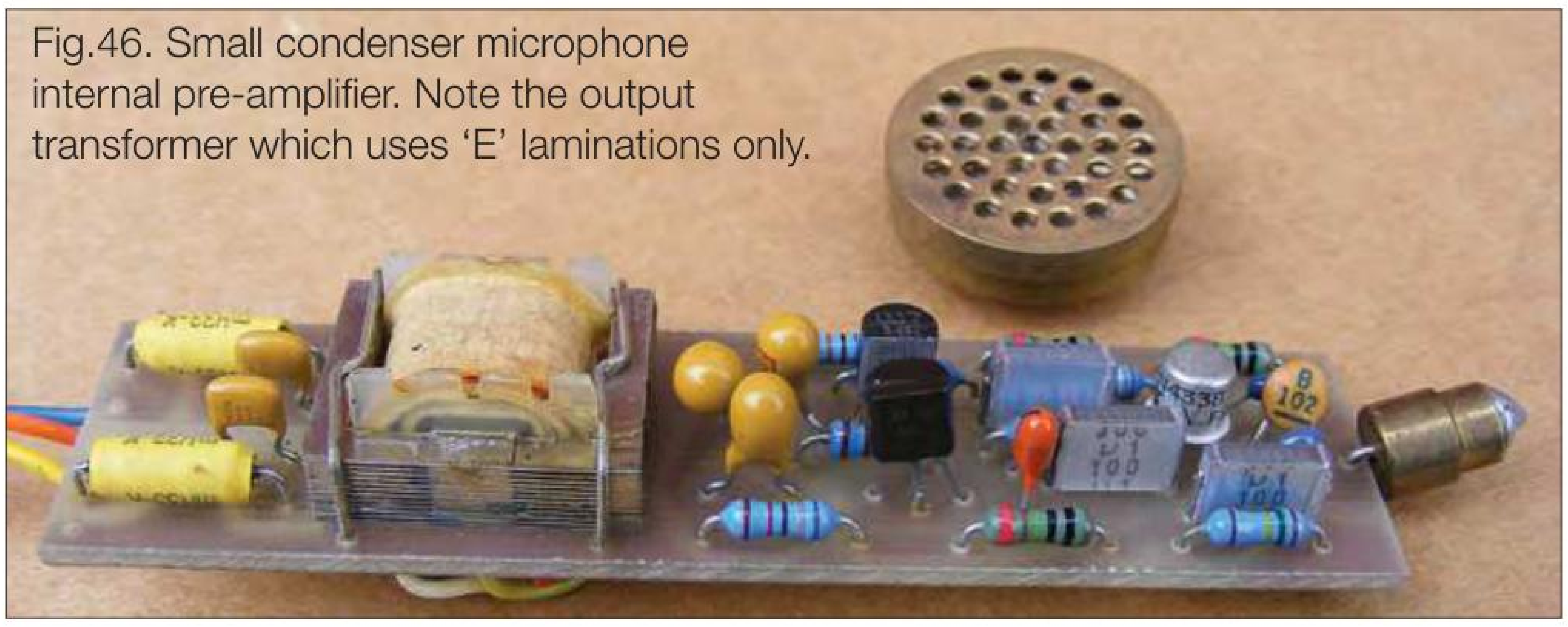

Fig.46. Small condenser microphone internal pre-amplifier. Note the output transformer which uses 'E' laminations only.

Note the Zobel network has different values for series and parallel connected secondaries respectively, 13nF and 1.8kΩ for series, and 6.8nF and 1.3kΩ for parallel.

The second board design (shown in Fig.43) is a dual-outline for both the VTX102-3001 and the bigger VTX-101-3002 output transformers. Again, provision for Zobel networks is provided, since I'm sick of hanging them on the output of XLR sockets. Fig.44 shows the assembled board for the 3001, and Fig.45 for the 3002 with the primaries wired in parallel to give a 1:1 ratio. When this transformer was used in the *Vocoder* output transformer driver (February 2022) the Zobel capacitor was 33nF because of the negative source impedance drive.

Interesting circuits

Finally, here's a round-up of a few interesting audio transformer circuits to whet your appetite / soldering iron.

Hebden Sound/Calrec condenser microphone.

I helped the late Keith Ming with this design many years ago. It shows what's hidden inside many condenser microphones (Fig.46). It's a 500MΩ input impedance, low-noise FET buffer followed by a modulated-current-source bipolar emitter follower with a bit of high-pass filtering to remove wind noise (Fig.47). Note how the transformer uses its centre-tap to harvest the phantom power from the incoming microphone lead for the electronics. The finished microphone is shown in Fig.48.

Dual parallel op amp transformer driver

The circuit in Fig.49 was developed to drive a VTX-101-007 600Ω balancing transformer while avoiding the addition of a complex push-pull output stage to provide the necessary current. Two 5534s with paralleled outputs can provide up to 80mA peak. The circuit has negative output resistance to reduce distortion. The prototype is shown in Fig.50.

Push-pull driver

This circuit takes the opposite approach to Fig.49 in that the transformer is driven

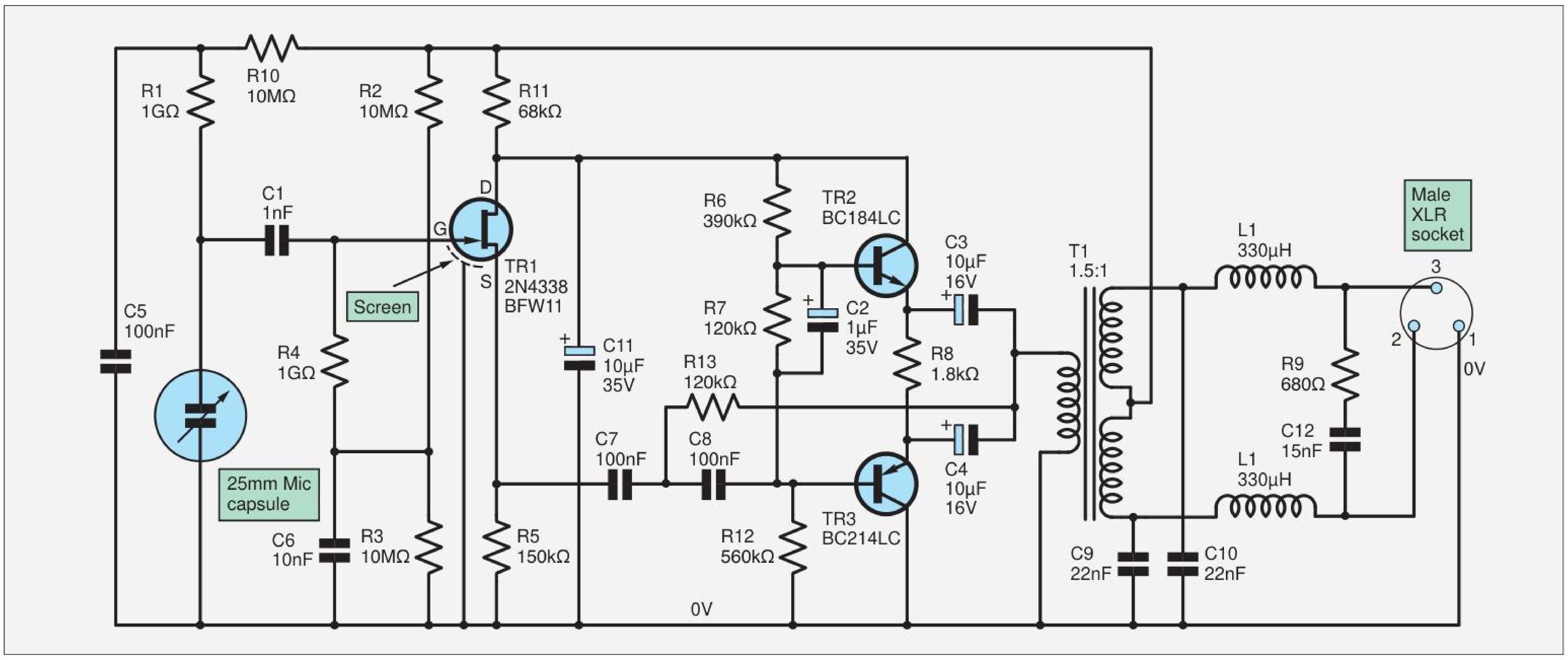
R1
1GΩ
R10
10MΩ
R2
10MΩ
R11
68kΩ
C1
1nF
D
G
S
TR1
2N4338
BFW11
Screen
C5
100nF
R4
1GΩ
25mm Mic capsule
C6
10nF
R3
10MΩ
R5
150kΩ
C11
10µF
35V
R6
390kΩ
R7
120kΩ
C2
1µF
35V
R13
120kΩ
C7
100nF
C8
100nF
R12
560kΩ
0V
TR2
BC184LC
TR3
BC214LC
C3
10µF
16V
R8
1.8kΩ
C4
10µF
16V
T1
1.5:1
C9
22nF
C10
22nF
L1
330µH
L1
330µH
R9
680Ω
C12
15nF
Male XLR socket
3
2
1
0V

Fig.47. Circuit for Hebden Sound/Calrec 1072 condenser microphone. Yes, those resistors are 1000MΩ (1GΩ).

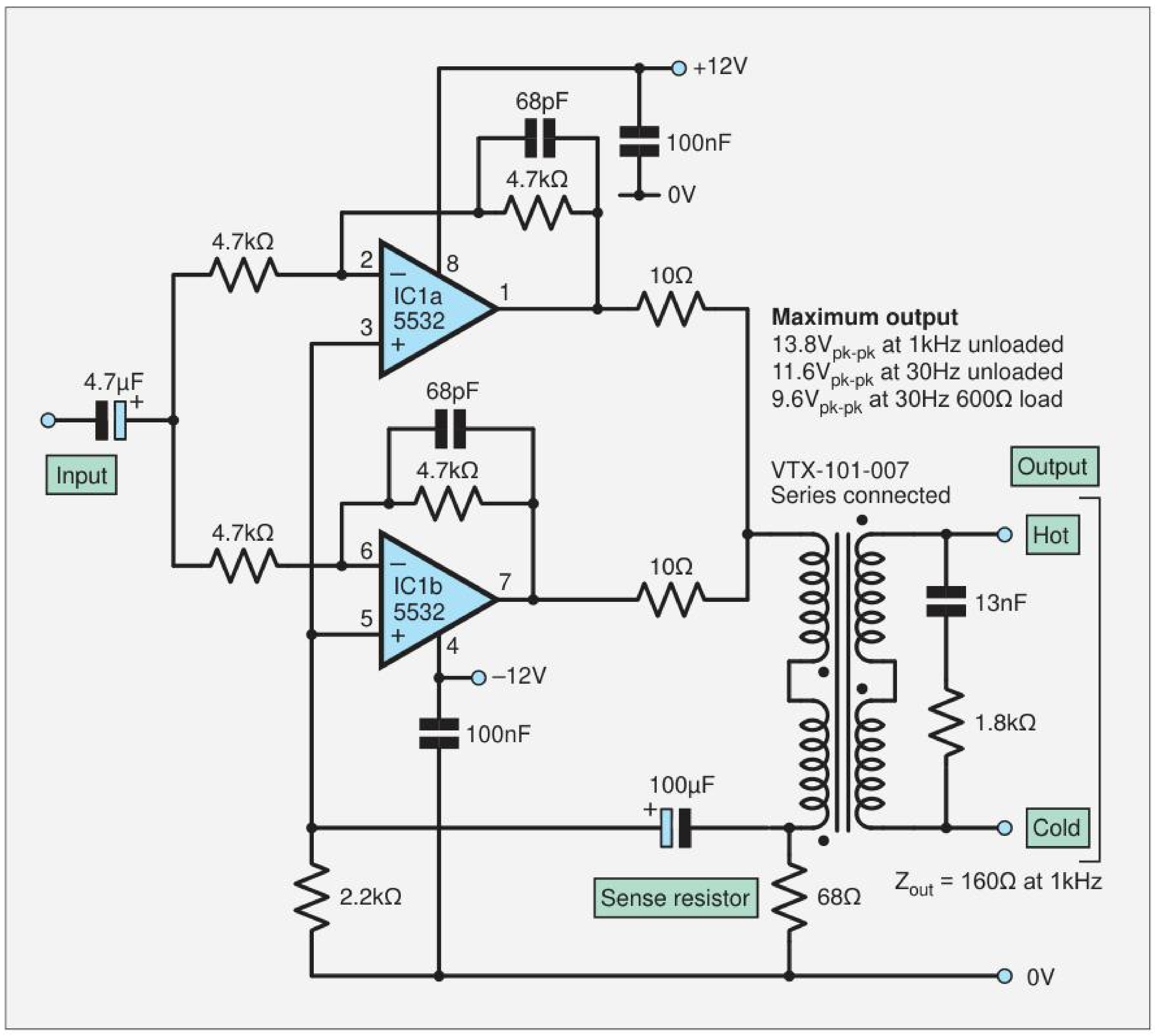
+12V
68pF
100nF
0V
4.7kΩ
4.7kΩ
2
8
IC1a
5532
3
1
10Ω
Maximum output
13.8V_{pk-pk} at 1kHz unloaded
11.6V_{pk-pk} at 30Hz unloaded
9.6V_{pk-pk} at 30Hz 600Ω load
4.7µF
68pF
Input
4.7kΩ
VTX-101-007
Series connected
Output
4.7kΩ
Hot
6
IC1b
5532
5
7
10Ω
13nF
4
–12V
100nF
1.8kΩ
100µF
Cold
Sense resistor
2.2kΩ
68Ω
Z_{out} = 160Ω at 1kHz
0V

Fig.49. Line output transformer drive circuit. Op amps are in parallel to double the output current to 80mA max.

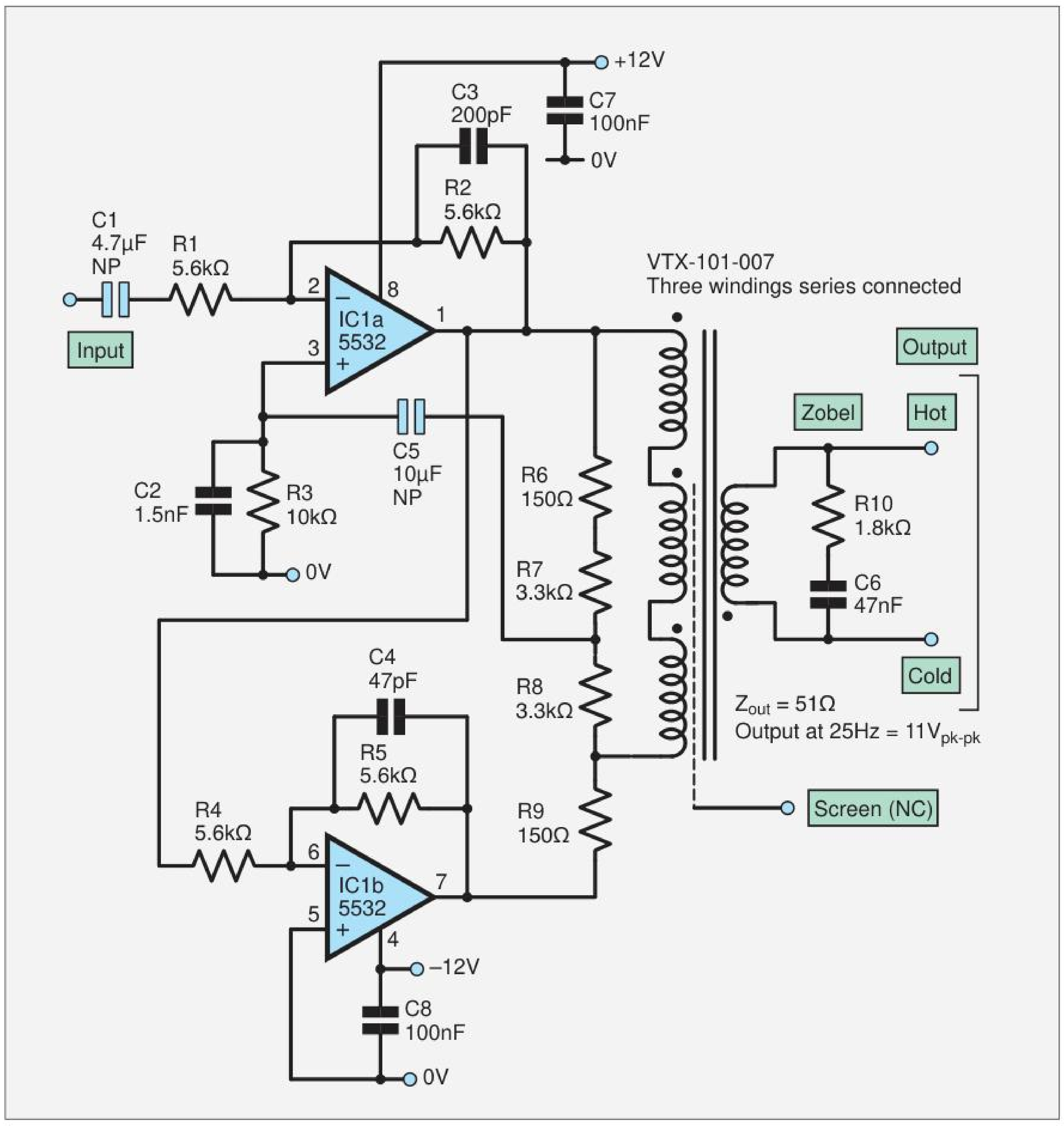
+12V
C3
200pF
C7
100nF
0V
R2
5.6kΩ
C1
4.7µF
NP
R1
5.6kΩ
2
8
IC1a
5532
3
1
VTX-101-007
Three windings series connected
Input
Output
Zobel
Hot
C2
1.5nF
R3
10kΩ
C5
10µF
NP
R6
150Ω
R10
1.8kΩ
0V
R7
3.3kΩ
C6
47nF
C4
47pF
R8
3.3kΩ
Cold
Z_{out} = 51Ω
Output at 25Hz = 11V_{pk-pk}
R5
5.6kΩ
R4
5.6kΩ
R9
150Ω
Screen (NC)
6
IC1b
5532
5
7
4
–12V
C8
100nF
0V

Fig.51. Bridge-tied load (BTL) transformer driver. This avoids distorted current going into signal ground.

by a bridged amplifier output. In this case the voltage swing is doubled and the output current is only 40mA. This means a step-down transformer is needed. This is achieved by connecting three of the transformer's windings in series, giving a 3:1 ratio, as shown in Fig.51. The advantage of this circuit is that no dirty current is sunk into the signal ground, it is confined to the power rails. Again, negative output resistance is provided, and this proved to be the trickiest part of the circuit to design. I had to cancel the common-mode signal using R7 and R8, leaving the voltage dropped on the sense resistor R9. The built-in interwinding screen now has no effect because one of the secondaries is used as part of the primary. However, this is less critical on an output (See the Veroboard circuit is shown in Fig.52.

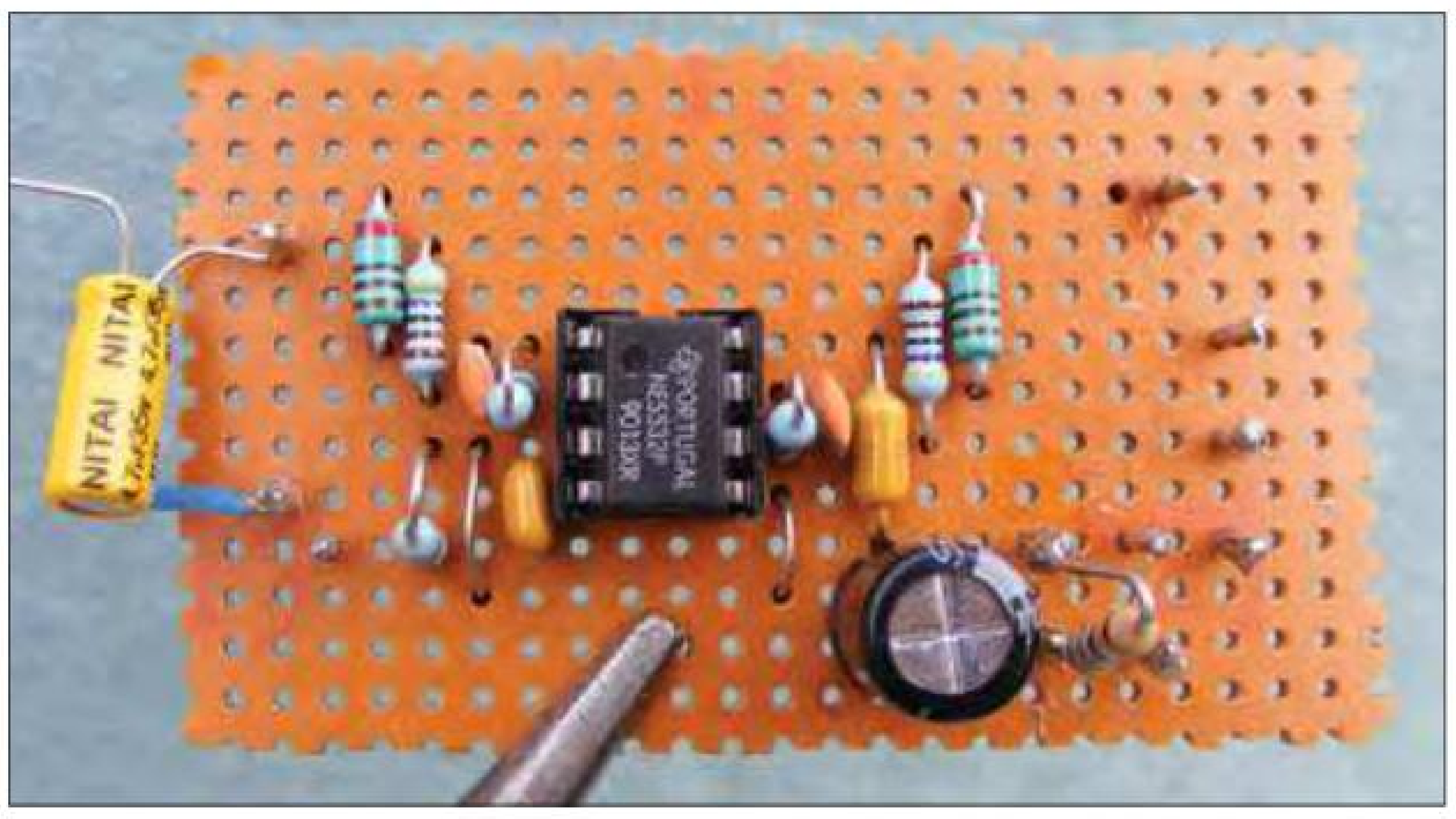

Fig.50. Photo of parallel op amp drive circuit.

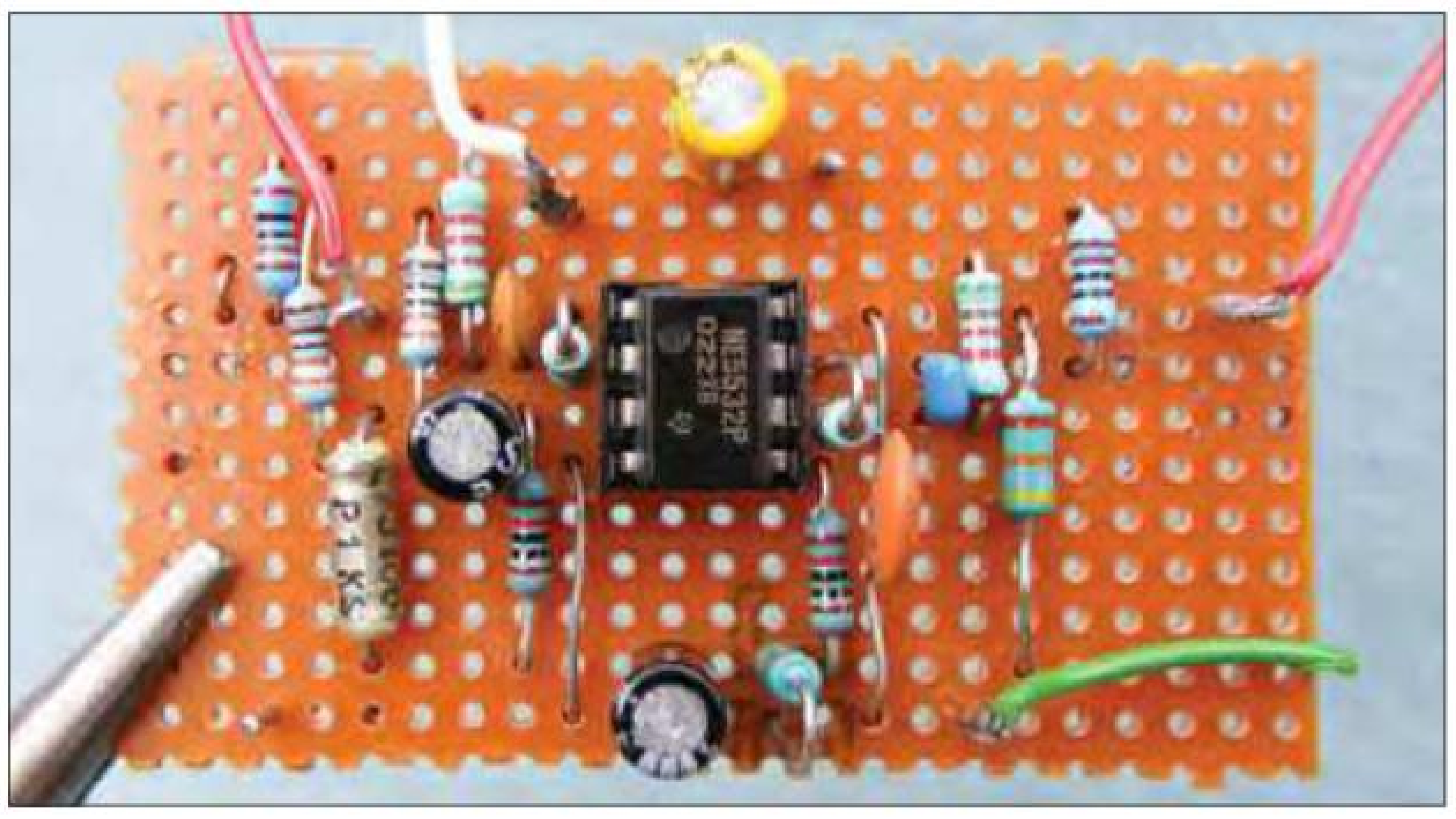

Fig.52. BTL transformer driver on Veroboard gives 11V_{pk-pk} at 30Hz from an 007 transformer, which is the highest output voltage possible without saturation.

Neve BA283 output amplifier

I have to include this circuit (Fig.53) since it has such a massive following among recording engineers. This is down to its wonderful harmonic character due to its 1960s single-ended topology and massive drive capability by virtue of a class-A 2N3055 running at 85mA. The output transformer costs almost £100 because it is huge and has a gapped core. It uses M6 silicon iron, not Mumetal, to get the +34dBu high level and to generate the third-harmonic distortion to complement the second-harmonic distortion generated by the amplifier. The PCB is shown in Fig.54. The full 'Neve' microphone pre-amp I built is shown in Fig.55.

Mid-dip balancer

Here's a simple circuit I devised for an edgy-sounding synthesiser that also had 50Hz buzz from power supply leakage. It uses the two tightly coupled secondaries from a T/T3 phase-splitter transformer to provide output isolation and balancing from the synthesiser output to the XLR socket shown in Fig.56. The primary, which is loosely magnetically coupled to the secondaries is tuned with a capacitor to remove some energy from the magnetic circuit in the midrange, thereby getting rid of the harshness. The step-up ratio allows a smaller capacitor value to be used.

Bass bumper

Normally, it is best to directly couple transformers to amplifier outputs. Occasionally, capacitor coupling can be used to advantage to give a 'bass boosting' effect, as shown in Fig.57. It's not real bass boost, it is

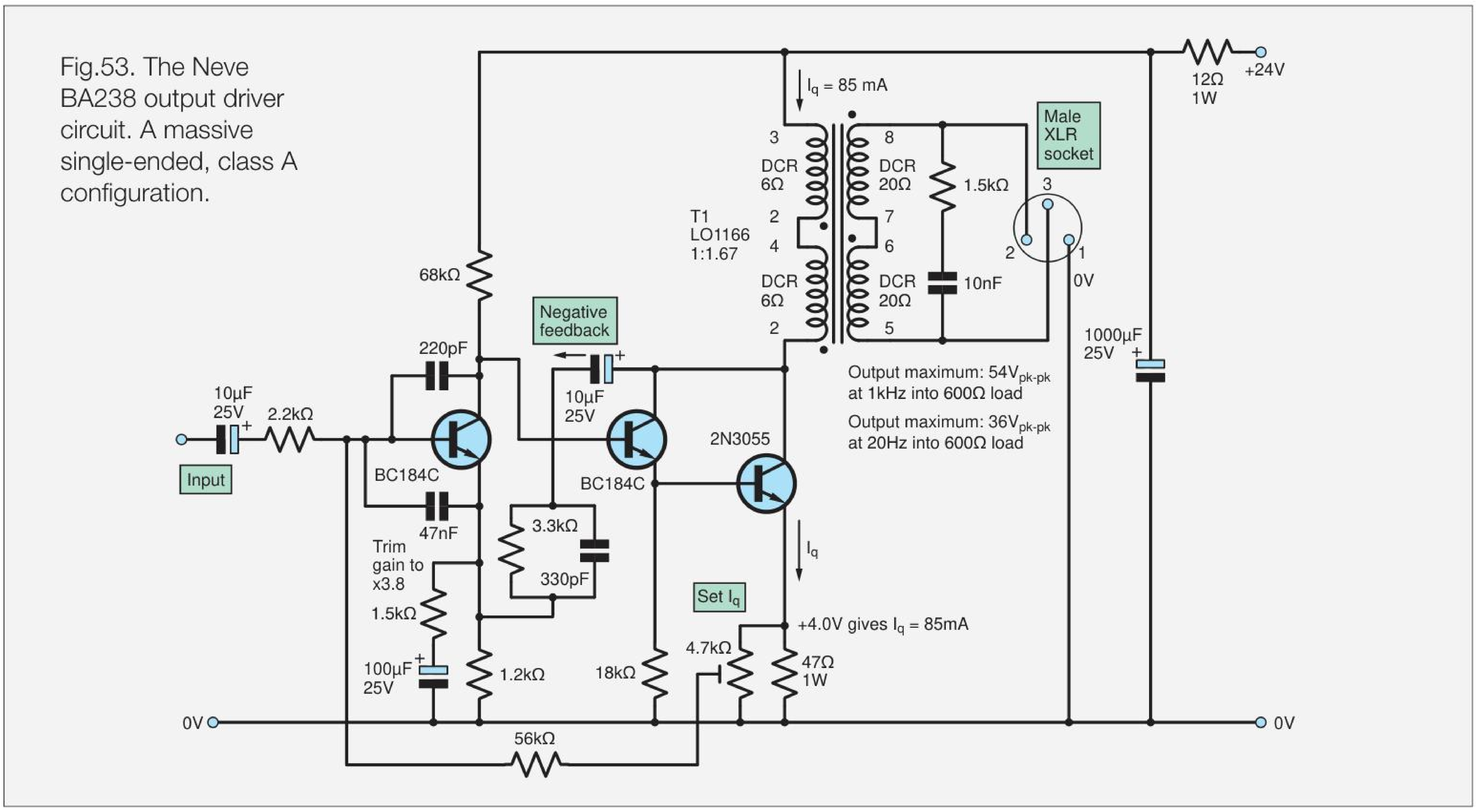

Fig.53. The Neve BA238 output driver circuit. A massive single-ended, class A configuration.

Iq = 85 mA
12Ω
1W
+24V
Male XLR socket
3
8
DCR 6Ω
DCR 20Ω
1.5kΩ
T1
LO1166
1:1.67
2
7
4
6
DCR 6Ω
DCR 20Ω
10nF
2
5
2
1
0V
68kΩ
Negative feedback
220pF
10µF 25V
1000µF 25V
Output maximum: 54Vpk-pk at 1kHz into 600Ω load
Output maximum: 36Vpk-pk at 20Hz into 600Ω load
10µF 25V
2.2kΩ
Input
BC184C
BC184C
2N3055
47nF
3.3kΩ
330pF
Trim gain to x3.8
1.5kΩ
Set Iq
Iq
+4.0V gives Iq = 85mA
100µF 25V
1.2kΩ
18kΩ
4.7kΩ
47Ω 1W
0V
56kΩ
0V

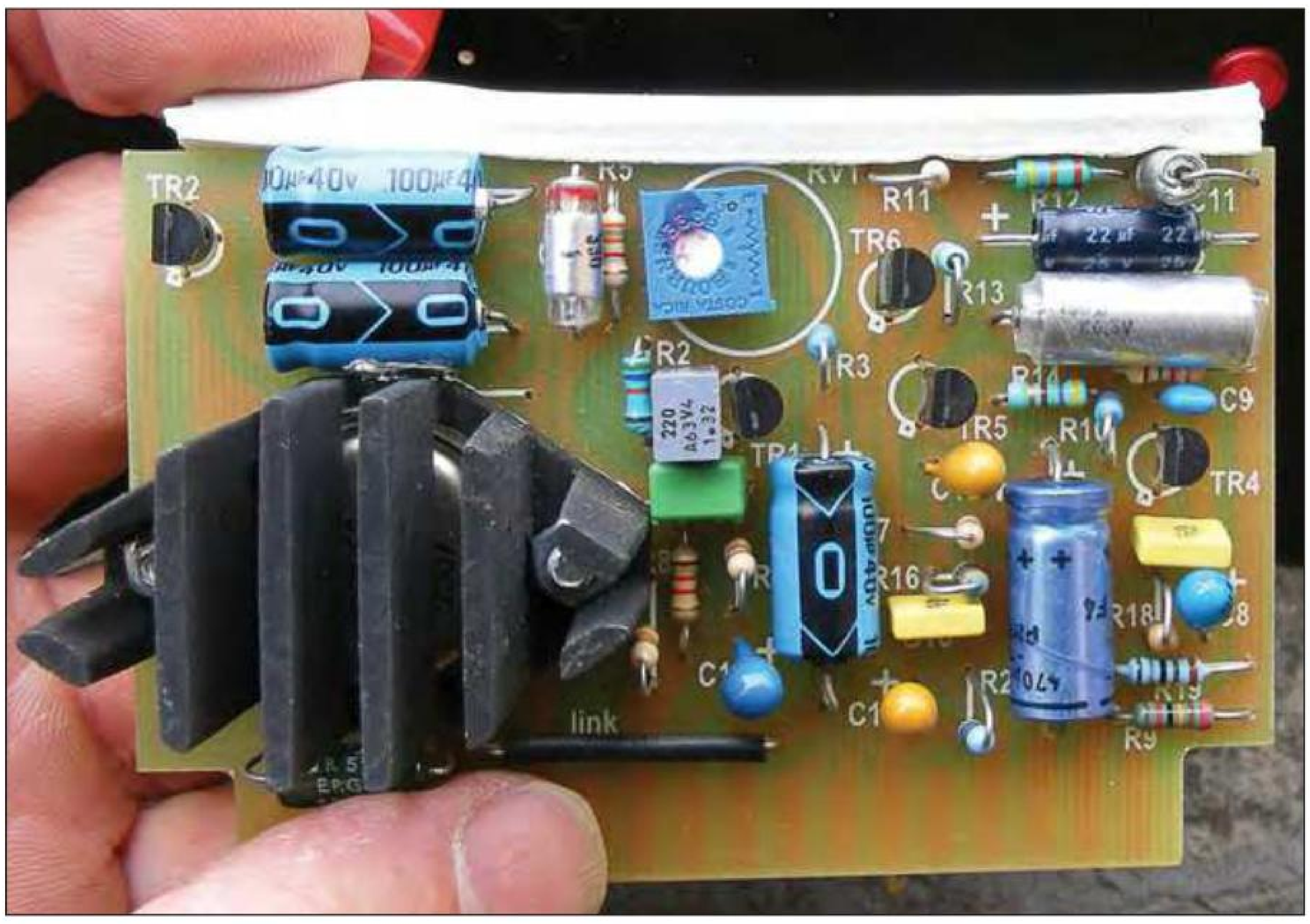

Fig.54. Neve BA238 output driver board. Note the uses of a TO3 output transistor: bomb-proof, good-sounding over-engineering.

TR2
R5
RV1
R11
TR6
R13
R2
R3
TR5
R10
C9
TR4
R16
R18
C1
link
R9

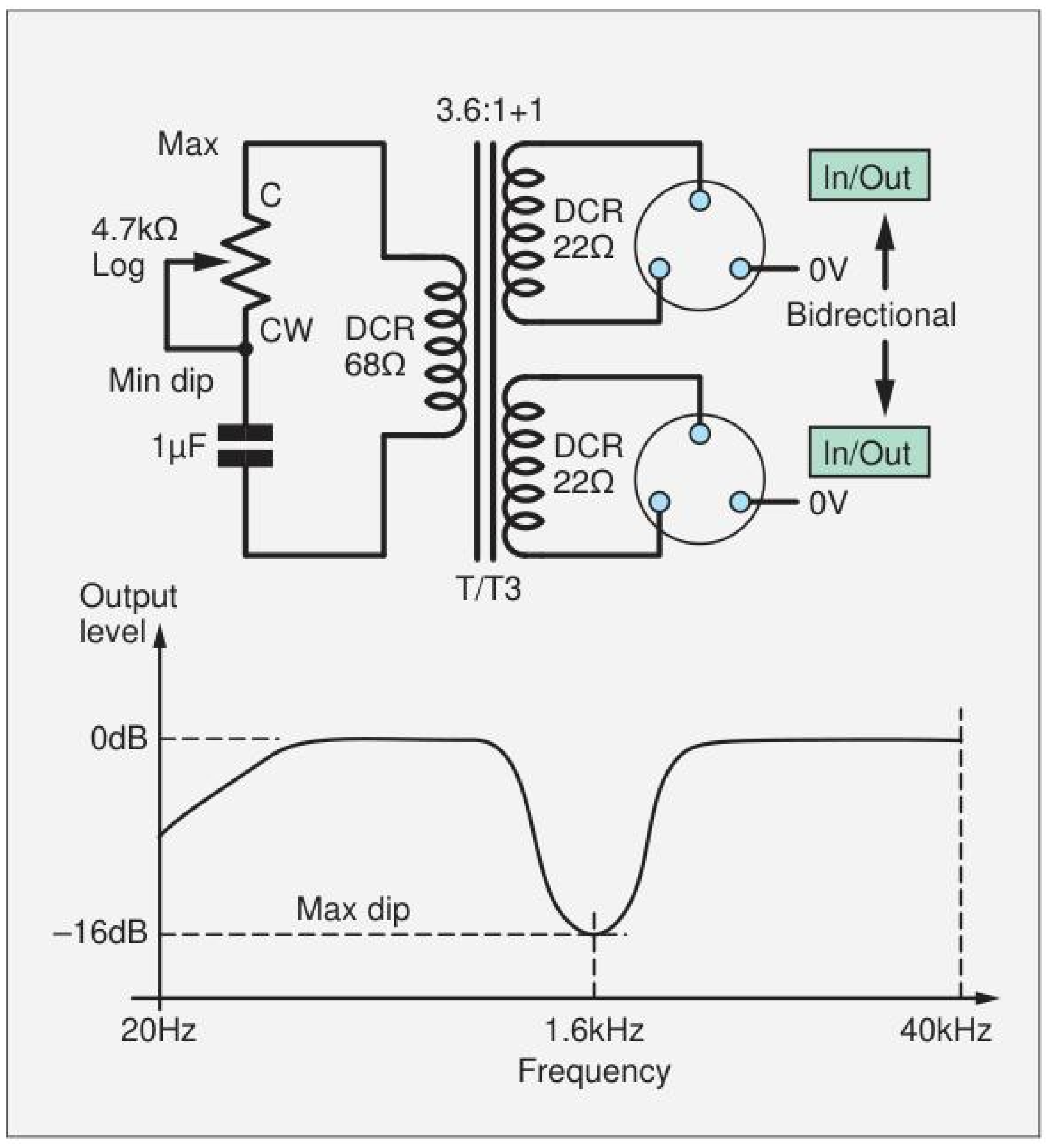

Fig.56. 'Mid dip' circuit – provides isolation and a 'smiley curve' at the same time.

3.6:1+1
Max
C
4.7kΩ Log
CW
Min dip
1µF
DCR 68Ω
DCR 22Ω
DCR 22Ω
In/Out
0V
Bidirectional
In/Out
0V
T/T3
Output level
0dB
–16dB
Max dip
20Hz
1.6kHz
40kHz
Frequency

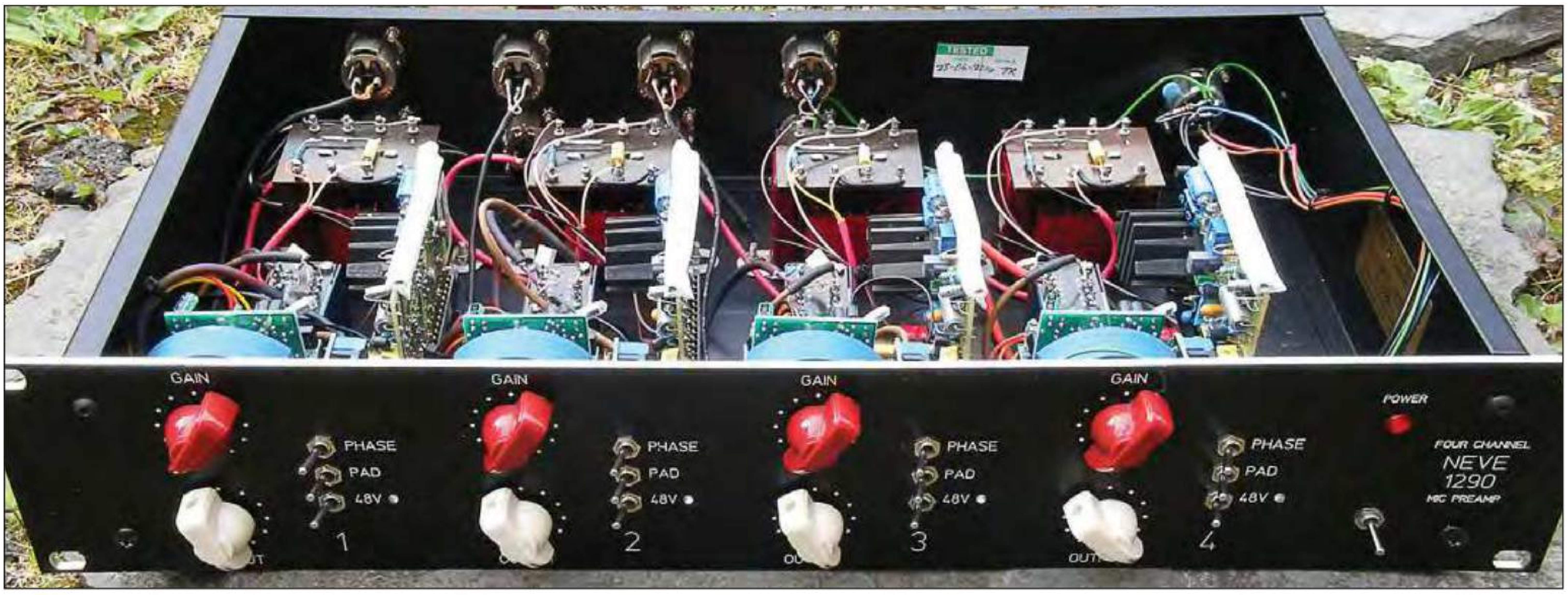

Fig.55. A completed 'Neve' microphone pre-amp built for Ed Lewis at Giant Wafer Studios. Note the row of four LO1166 transformers.

TESTED
GAIN
PHASE
PAD
48V
1
2
3
4
POWER
FOUR CHANNEL
NEVE
1290
MIC PREAMP

an under-damped high-pass filter with rising distortion below 1kHz (see Fig.58 and Fig.59). This gives the illusion of more bass. I used it on a broadcast microphone to get more gravitas by boosting sub-70Hz signals. People weren't fooled, I'm still five foot six!

Austerity audio

In these straitened times, sometimes only a cheap stripboard circuit will do just before the electricity gets cut off and the iron goes cold. Fig.60 shows the simplest class-A amplifier of the type I built when I was a kid. It has standing current through the output transformer, so a gapped or butt-jointed core is needed. The Repanco T/T4 shown in Fig.61 fits the bill perfectly. I remember nagging my mum to buy the little yellow box from the local TV shop. Then I found they had marked up the RS catalogue price 100%.

Another application was to make a a little test tone oscillator using the ubiquitous LT700. Here, the output transformer doubled as an inductor to make a resonant circuit for a Hartley oscillator –see Fig.62.

That's enough audio transformers for now! I hope you'll agree they are a vital if often overlooked component. We will inevitably return to them, but not for a good few months!

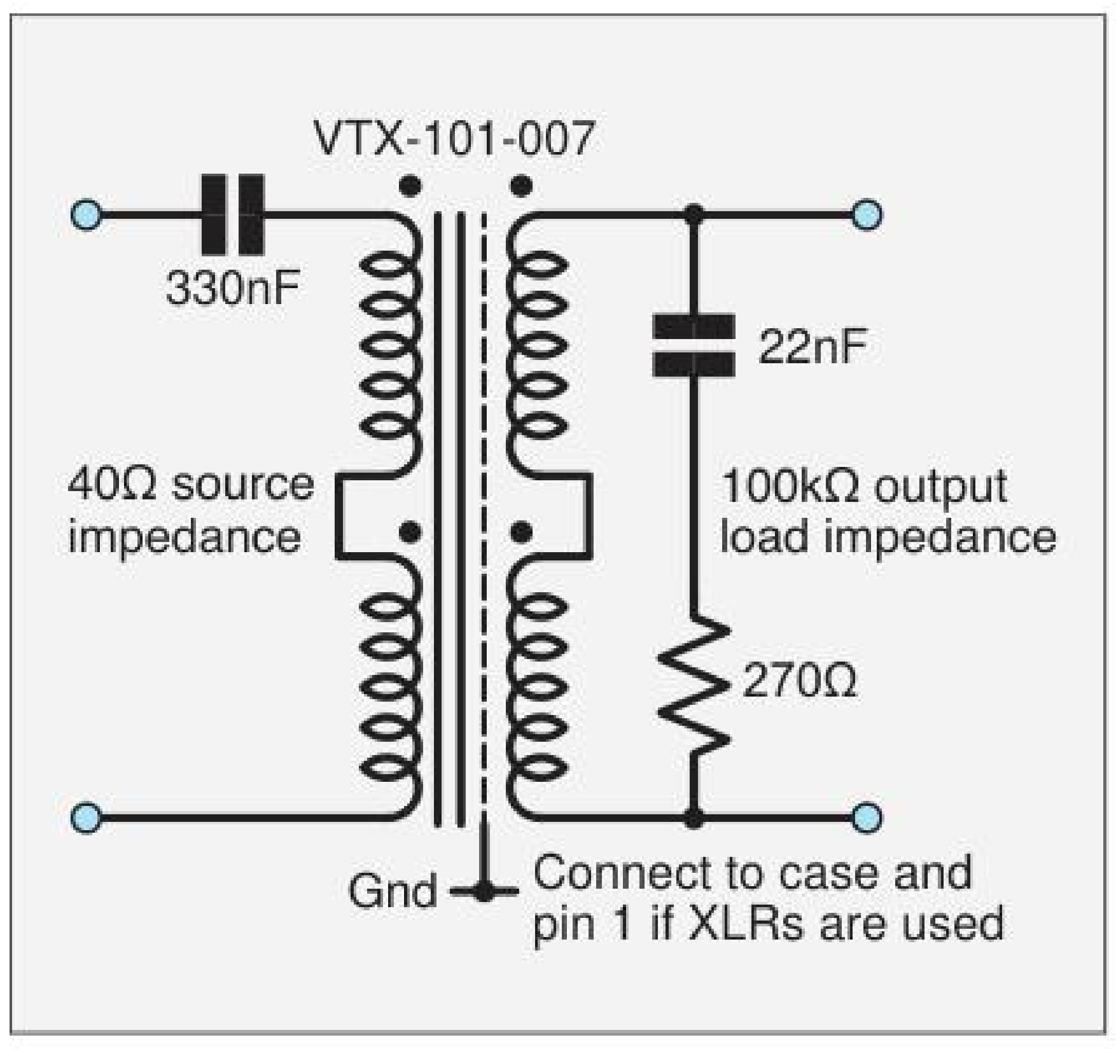
VTX-101-007
330nF
22nF
40Ω source
impedance
100kΩ output
load impedance
270Ω
Gnd
Connect to case and
pin 1 if XLRs are used

Fig.57. A transformer circuit that provides isolation, 'bass bumping' and a bit of 'top-end peaking'.

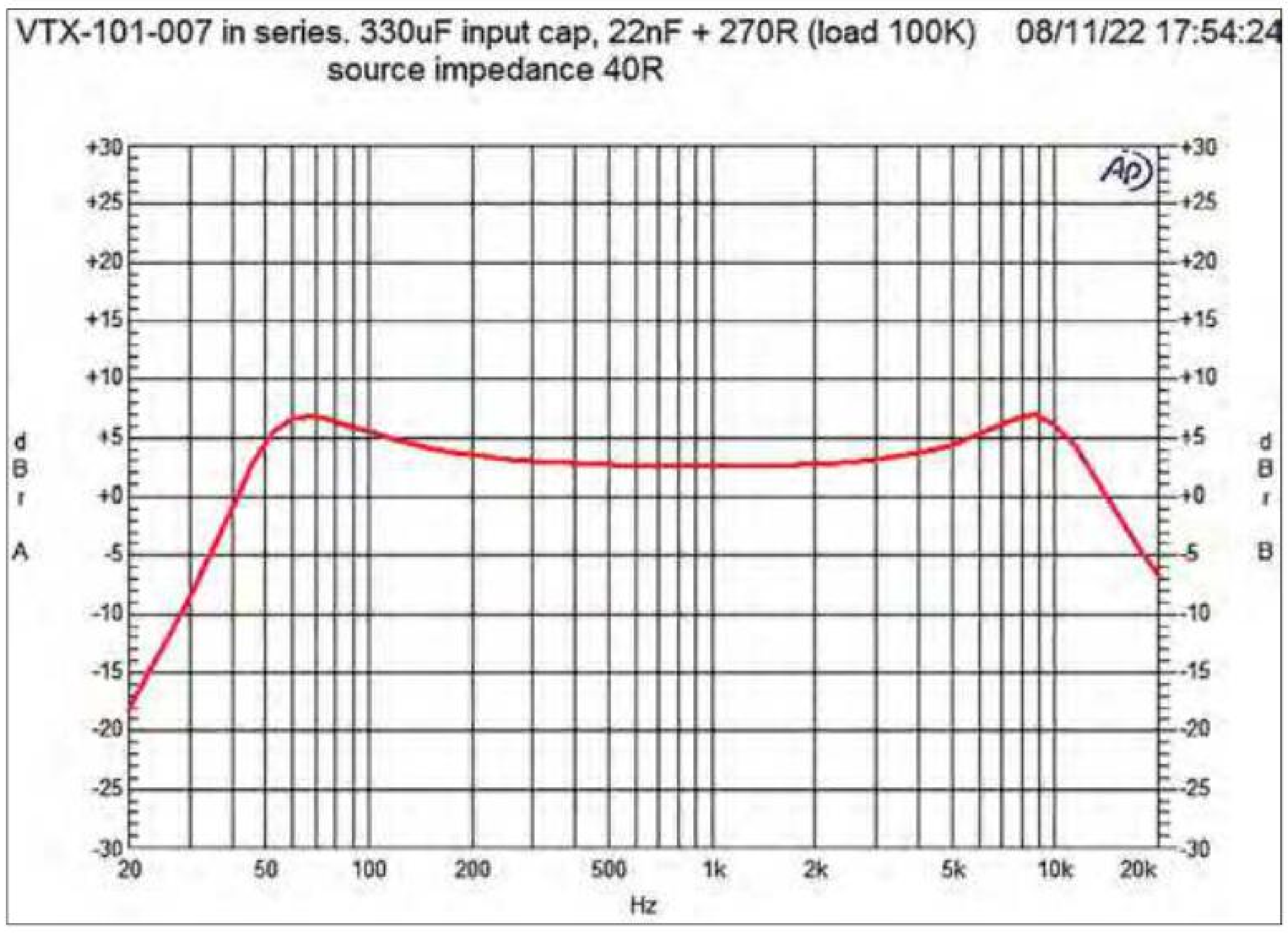

Fig.58. The frequency response of the circuit in Fig.57. Call it what you will, 'boom 'n' tizz' or my new name, a 'cats ears' curve.

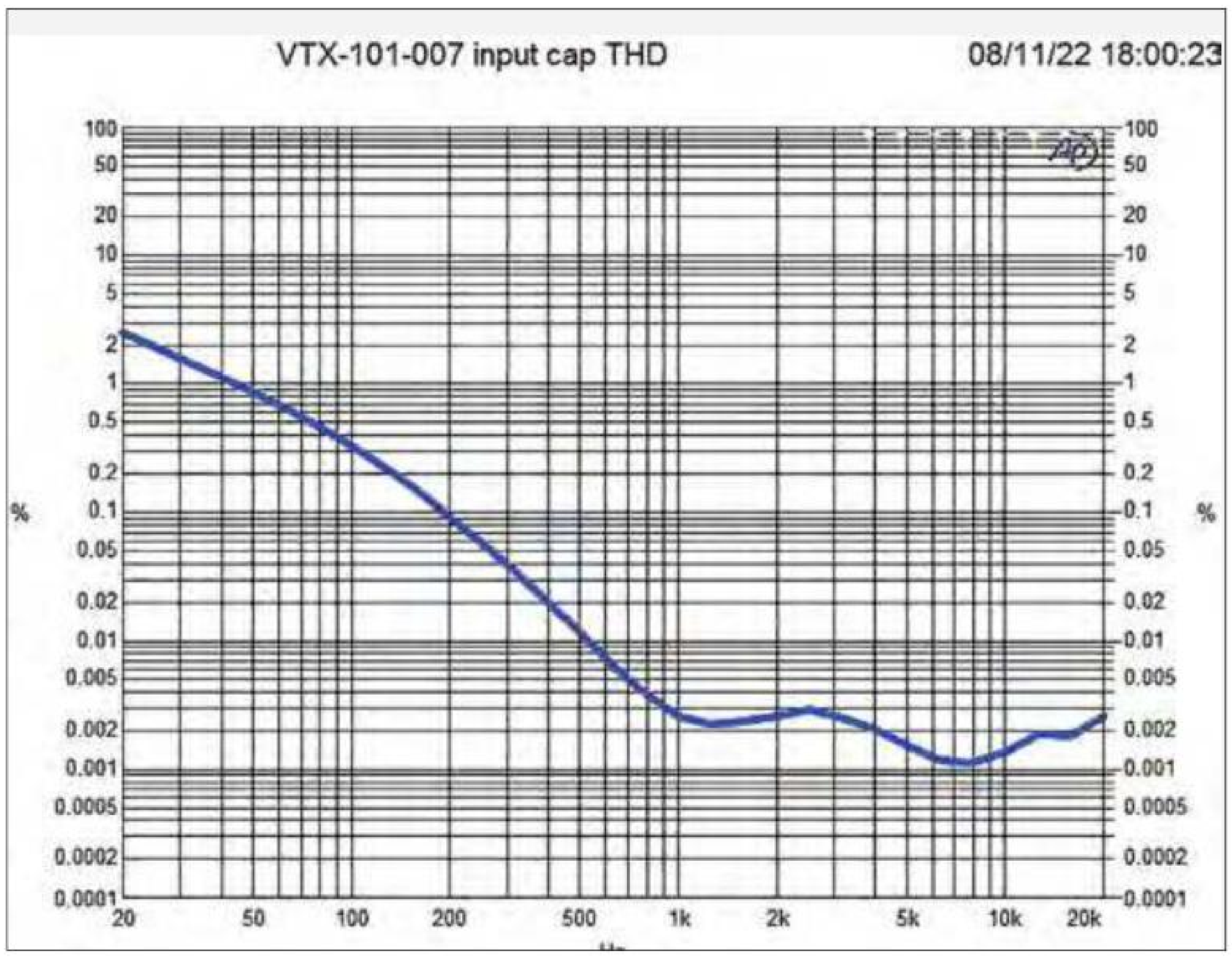

Fig.59. Driving a transformer from a high source impedance raises distortion. Feeding it through a 330nF capacitor (as in Fig.57) causes a steep rise in distortion with decreasing frequency. Transformers already exhibit rising distortion in the bass, so this circuit gives an exaggerated transformer effect. (0dB input, 100kΩ load, 40Ω source)

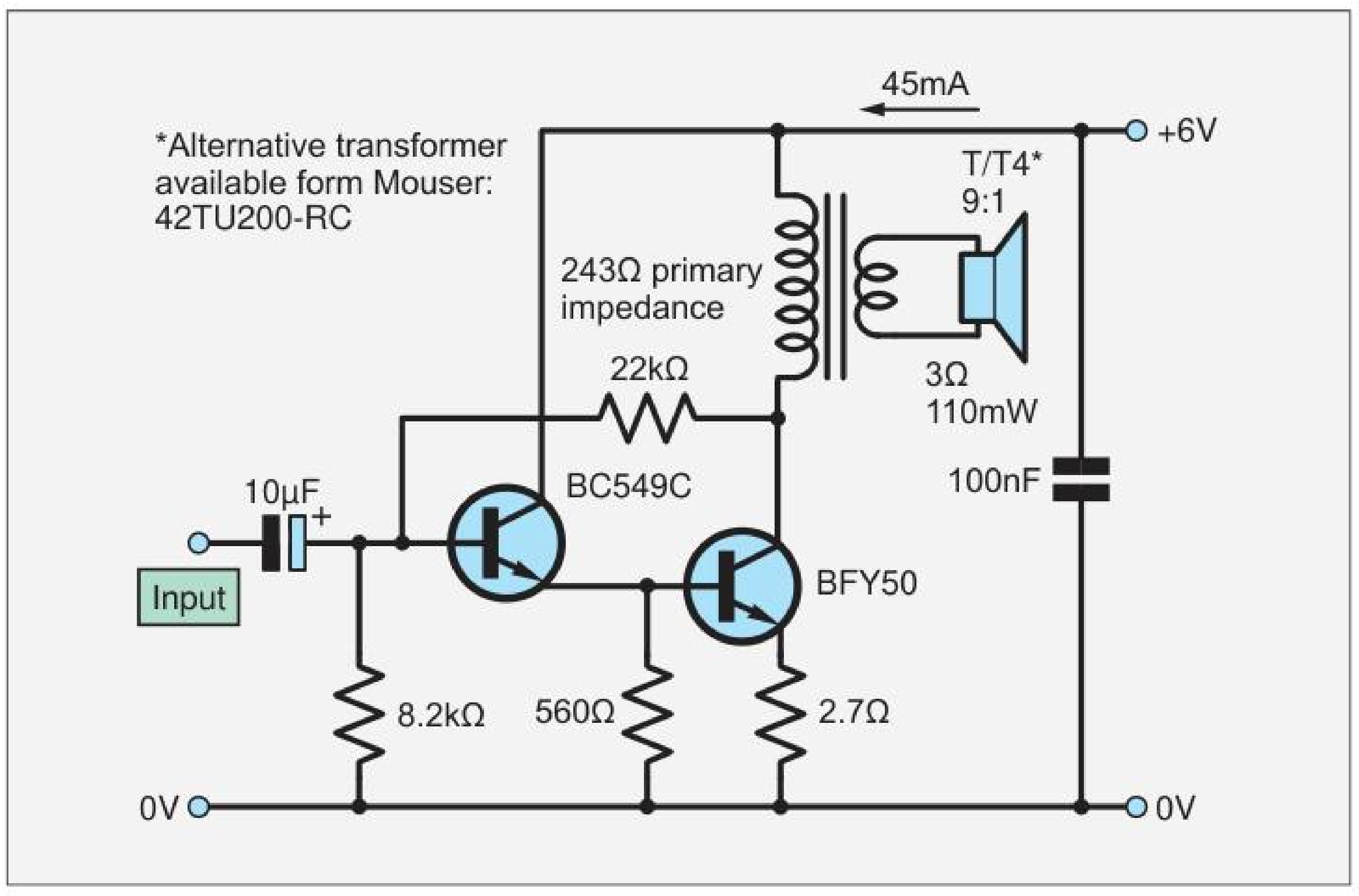
*Alternative transformer
available form Mouser:
42TU200-RC
45mA
+6V
T/T4*
9:1
243Ω primary
impedance
22kΩ
3Ω
110mW
100nF
10µF
+
BC549C
Input
BFY50
8.2kΩ
560Ω
2.7Ω
0V
0V

Fig.60. An affordable class-A amplifier circuit. Very popular in magazines like *Practical Wireless* in the late 1960s. *PE* did a germanium transistor version of this in April 1969. However, it only supplied 50mW output!

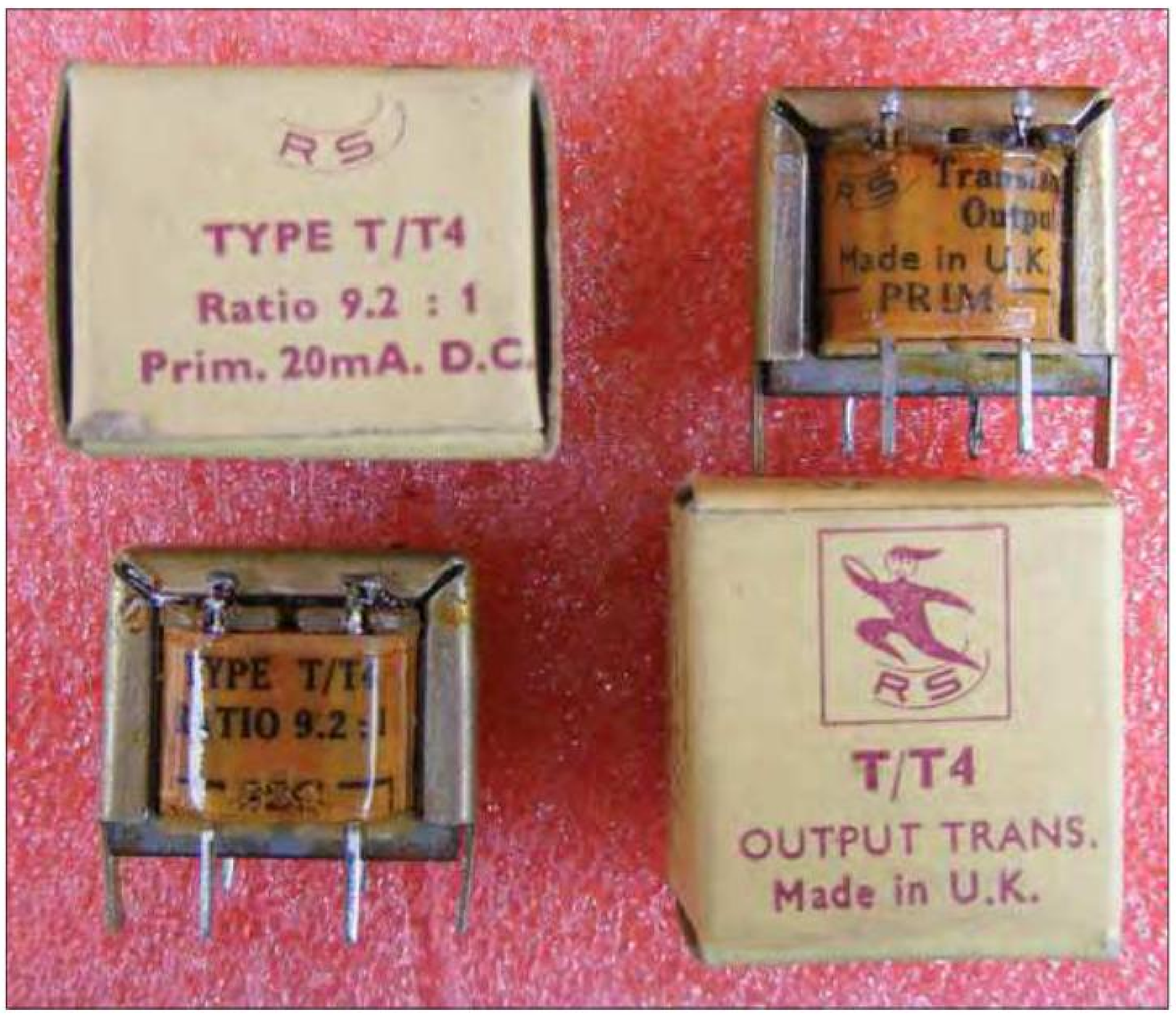
RS
TYPE T/T4
Ratio 9.2 : 1
Prim. 20mA. D.C.
Made in U.K.
PRIM.
TYPE T/T4
RATIO 9.2 : 1
RS
T/T4
OUTPUT TRANS.
Made in U.K.

Fig.61. Transformer for the little class-A amp in Fig.60. I've had one of these in my junk box, sorry: 'strategic research and development inventory', since 1972.

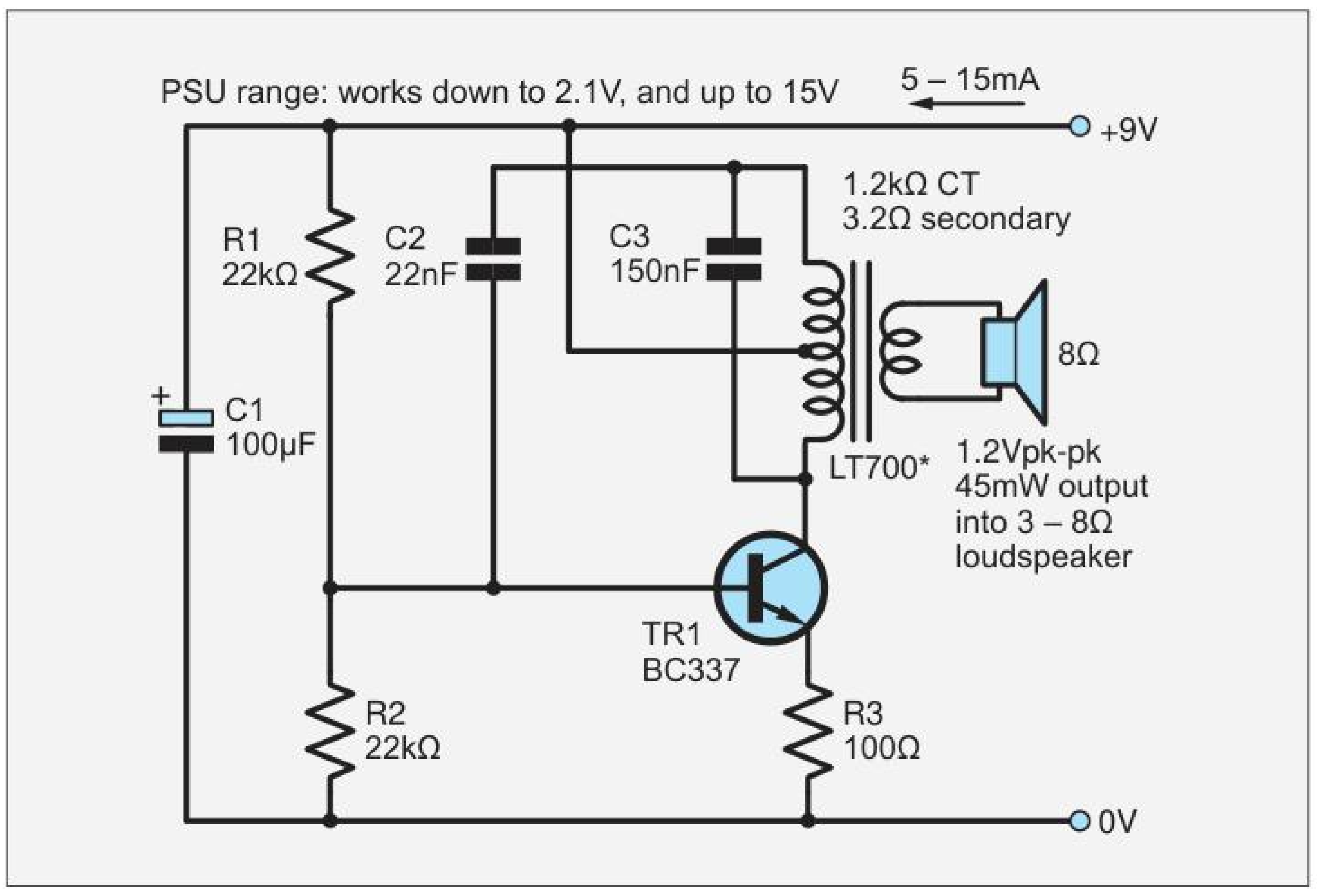
PSU range: works down to 2.1V, and up to 15V
5 – 15mA
+9V
1.2kΩ CT
3.2Ω secondary
R1
22kΩ
C2
22nF
C3
150nF
8Ω
+
C1
100µF
LT700*
1.2Vpk-pk
45mW output
into 3 – 8Ω
loudspeaker
TR1
BC337
R2
22kΩ
R3
100Ω
0V

Fig.62. A cheapie circuit that cheeps – a 1kHz crude sinewave LT700 test-tone oscillator.

AOShop

The home for specialist audio, analogue and historic components – provided by Jake Rothman, *PE's Audio Out* columnist. The AOShop is your best bet for classic analogue 'NOS' (new old stock) components, including all parts for *Audio Out* projects and designs.

Ge semiconductors

Small-signal PNP transistors

AC125, NKT214F, OC57 OC59	£1.00

Low-noise PNP transistors

GET106	£2.50

Small power PNP transistors

AC153, AC153K, AC188	£1.50

High-voltage PNP transistors

OC77, CV7001, ACY20	£1.50

TO3 PNP power transistors

OC22, CV7054 (OC23), OC25, OC35, OC36, AD143, AD149, AD161, AD162	£2.00
AD140	£3.50
AD149 matched pair	£5.00

RF PNP transistors

OC41, OC42, 2SA12, 2SA53,AF124, AF128, GET872A	£1.50

NPN transistors

OC139, OC140, ASY73, AC141K, AC176K, AC176	£2.00

Diodes

CV7049 (OA10), CG92 (OA91)	£0.50

Si semiconductors

Diodes

ZC5800 RF Schottky	£0.20

Low-noise silicon transistors

BFW16A, 2SC3071	£1.50
2SC2204, 2SD655	£0.50
ZTX651	£0.30

RF transistors (suitable for Theremin)

BF199	£0.50
BF245	£0.60

Audio power MOSFETs

Exicon 10N20, 10P20	£6.50
Hitachi 2SJ99, 2SK343	£3.50
Hitachi 2SJ 50, 2SK135	£7.00
Hitachi 2SJ56, 2SK176	£8.50

JFETs

BFW11, BFW10, TIS73L, J177, J113, U1994, U1898, 2SJ176	£1.00

MOSFETs

ZVP2106A	£0.30
Dual-gate 3SK45, BFS28	£1.50

Metal-cased transistors

BC143	£0.35
2N1711	£0.50
BCY71	£0.30
BC109C	£0.60

Amplifiers

TL082 dual JFET input op amp	£0.25
LM318 high-speed op amp	£0.35
µA709 metal-cased op amp	£2.00
5534H metal-cased op amp	£3.00
LM384, TDA2030A	£1.50
TAA435 (power amp driver)	£1.20

Synthesiser ICs

That/dbx 2180 VCA/VCF	£6.00
CA3080 VCA/VCF (vocoder)	£2.80
CA3082 VCA/VCF	£4.00
LM13600/ LM13700 VCA/VCF	£2.00
CA3086 transistor array	£1.00
PT2399 echo/delay	£1.50

Dual transistors

2N2639, 2N2223, 2N2910 (NPN)	£4.00
E401 (JFET)	£4.00
DMMT3904/6	£0.50

Loudspeakers

PE Mini-Monitor

Volt PE165 6.5-inch woofer (each)	£85
Morel MDT29 tweeter (each)	£25
Kit *pair* of PE165/MDT29 plus Volt crossover parts and PCBs	£299
Monacor DT-28N tweeter (each)	£45
Vifa 19mm BC20SC15-04 tweeter (each)	£15
Volt PE110 5-inch woofer (each)	£75

Volt crossover inductors

1.2mH, 1.5mH, 2mH, 2.7mH, 0.5mH (tapped at 0.3mH) (each)	£5.85
LS3/5A transformer-core 15Ω assembled crossover board (each)	£60

Fully assembled and tested high-quality speaker prototypes – ask for details

LS3/5As and other similar speaker systems (pair)	£200-£350

Fully tested reclaimed speakers

Vifa BC14 5-inch woofer (each)	£15
Vifa TC26 1-inch tweeter (each)	£15

Low-price speakers

Celestion elliptical 6x4-inch 5Ω (Robert's Radio)	£3.50
Philips 4-inch 4070	£2.00
EMI 10x6-inch, 30Ω Alnico	£10
64mm 64Ω neodymium	£1.20
3.5-inch 25Ω	£3.50
5x3-inch elliptical 50Ω or 80Ω Alnico	£3.50
1.65x2.75-inch 8Ω	£1.50

Can't see what you want? Just ask – we have a huge stock of inexpensive high-quality parts!

Capacitors

Note '10/63' denotes '10µF 63V'.

Polyester

3.3/100, 4.7/250, 4.7/63	£1.00
5.6/63, 8.2/63, 10/63	£2.00
Mullard 'Mustard' C296 0.22/400	£2.00

Polycarbonate

Axial 2.2/63 1%, 4.7/160, 6.8/63	£1.00

Radial

6.8/160V, 10/63	£2.00
Reclaimed 22/63	£2.00

Polystyrene

Philips 1% 4.7nF/160, 6.2nF/500, 12nF/63, 22nF/63, 110nF/63	£1.00
RIFA 1% 100nF/100	£2.00
Suflex 2.5% 10nF/63 (rad. or ax.)	£0.50

Radiation resistant

Siemens cellulose acetate MKL 2.2/25	£0.80

Electrolytic – Mullard blue 017 series

10/25, 22/25, 100/10	£0.50
150/40, 470/40,1000/40	£1.00

Tantalum – metal cased

22/50, 47/35, 68/25, 100/20, 120/10, 150/16, 220/10, 330/6	£2.00
22/35, 33/35, 47/20, 68/15, 100/10, 150/6	£1.25
4.7/50, 6.8/35, 10/25, 10/35, 22/15	£1.00

Moulded-case tantalum

Kemet axial 6.8/10	£0.30
Kemet radial 33/10	£0.40
STC radial 100/20	£1.50

Tantalum bead

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470/3	£2.00
680/6.3	£3.00

Wet tantalum

220/25 axial	£3.20
Castanet button 140/30, 470/3	£3.20
Hughes 540/10	£3.20

Bipolar

Hermetic bipolar tantalum 16/35	£3.20
Callins Elcap wet aluminium 10/50	£0.50

Philips solid-aluminium (axial) 121/123

47/16	£1.00
330/6.3	£2.00
100/35	£4.00

Philips Pearl 122 series (radial)

10/16	£0.30
10/25	£0.50

Silvered mica (radial)

4.7nF/500 5%	£1.00

Trimmer capacitors

Vishay plastic-film 4-40pF	£0.80
Vishay plastic-film 5.5-45pF	£1.00
Vishay plastic-film 5-80pF	£1.20
Vishay plastic-film 10-250pF	£2.00
Mica 1-12pF, 2-40pF	£1.00

Audio transformers and inductors

Eagle transformers

LT44, LT722 driver, LT700, LT723 500Ω output	£2.50
LT30 500mW output	£3.50

Repanco

T/T3 splitter transformer	£4.00
CH2 5mH RFC	£2.00

Balanced output transformer

Vigortronix 600Ω VTX-101-007	£10
Vigortronix 600Ω VTX-101-3001	£10
Vigortronix 600Ω VTX-101-3002	£15
Gardners 150Ω	£10
Reclaimed BBC LL74/MPC nickel core 600Ω	£12

Reclaimed mic input transformer	£15

Inductors

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7-inch ferrite rod with MW and LW windings	£3.00

Special resistors

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Thermistor RA53, A13	£4.00
Thermistor CZ1, CZ6	£1.50
Holco H2 2.2MΩ 1W, 1%	£1.00
Welwyn 1GΩ 2W	£1.00
Allen Bradley 1.2kΩ 2W C-comp	£1.00

Lots of big valve resistors available.

Potentiometers

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25kΩ lin cermet	£2.00
25kΩ lin conductive plastic	£3.00

Plessey moulded-track

5kΩ log with switch	£3.00
50kΩ A/log	£3.00
Mil 250kΩ lin dual	£5.00

Alpha

16mm 4.7kΩ A/log	£0.80
220kΩ A/log	£0.80
10kΩ lin centre-detent dual-gang	£1.50

Allen Bradley J series/Honeywell 10kΩ lin 1 million cycles	£5.00
Blore Edwards AB 45 dual 5kΩ A/log with switch	£3.50
Alps RK9 dual-gang 5kΩ RD law	£4.00
BI P260 500kΩ log conductive plastic 1 million cycles	£3.00
Colvern wire-wound 100kΩ or 50kΩ dual-gang 3W	£8.00
Mil Spec hermetic 10Ω	£8.00

Miscellaneous

Theremin Clearance Sale!

Elysian Theremin MIDI box	£300

PCBs

Pocket Theremin (*EPE*, 1996)	£4.00
Elysian Theremin (*EPE*, 1996)	£12
Synth VCF, VCO (*EPE*, 2017)	£3.00
48V PSU (*EPE*, 2019)	£3.00

Relays

STC hermetic 4190 24V DPDT	£4.00

Switches Blore Edwards/Plessey

MH1 4-pole 3-way	£3.00
Elma 01 2-pole 6-way	£6.00
3PDT guitar pedal stomp switch	£2.50

Valves

EC88, PCL84	£3.00

Robert's Radio modules

Tuners LP1169, LP1179	£7.00
IF strip LP1171	£7.00

Knobs – large Bakelite

Bulgin 1960s and Sifam 1970s	£1.50

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The Old Rectory, Arlais Road,
Llandrindod Wells, Powys
LD1 5HE (visit by appointment)
+44 (0)1597 829102
jrothman1962@gmail.com

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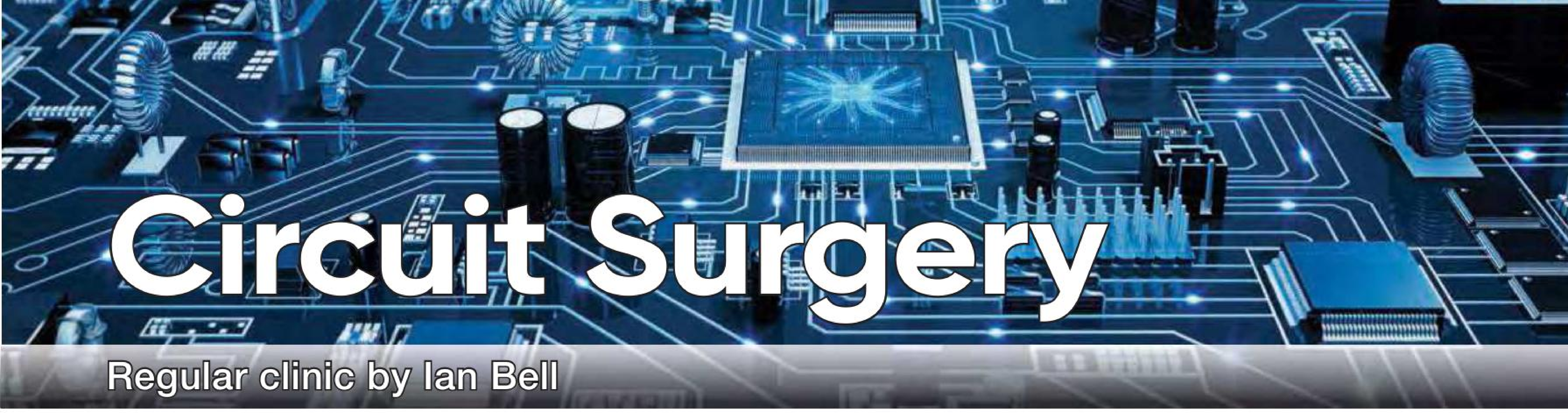
Big boxes and overseas at cost – ask for a quote



Circuit Surgery

Regular clinic by Ian Bell

Electronically controlled resistance – Part 3

In the previous two issues we discussed electronically controlled resistance, focusing on the use of JFETs (Junction Field Effect Transistors) as voltage-controlled resistors. First, we looked at the basic characteristics of the JFET that make it suitable for this task. Then, last month, we covered details of a variable attenuator in which a JFET takes the place of one of the resistors in a potential divider. We discussed the impact of the JFETs characteristics on the design and performance of this circuit, including use of feedback to reduce distortion caused by the JFETs non-linearity. Finally, we looked at examples of circuits in which the JFET attenuator is combined with op amps to create a voltage-controlled amplifier, often known as a 'VCA'.

Such voltage-controlled amplifiers have a number of uses in both audio and radio frequency circuits. In radio they can be used for AGC (automatic gain control) so that a radio receiver can adapt to varying signal strengths. In audio, they have a number of specific uses, such as noise gates and muting circuits, which reduce or modify the gain of an amplifier when no signal is present to prevent noise being very audible, or to cut the volume of background audio (eg, music) when a main signal is present (eg, a spoken announcement). They are used in music synthesiser envelope shapers, which control how the loudness of a note varies over time after is its played (eg, how long a note takes to fade after a keyboard key strike). Another important use of voltage-controlled amplifiers in audio is in limiters and compressors, and this what we will focus on this month because, at least historically, this is an important use of JFETs as electronically controlled resistors. Of course nowadays a lot of modern audio processing is done using digital signal processing (DSP) hardware or software; nevertheless, it is interesting to consider how JFET-based circuits work. There are numerous ways to implement voltage-controlled amplifiers other than using JFETs as variable resistors, but here we will stick with our current interest in the JFET approach.

Before discussing how to implement a compressor or limiter we need to describe what they do and define their basic characteristics. Having done that, we will discuss their operational principles, focusing on the role of the JFET variable resistor in these circuits. We will not cover full design details and the complexities of different possible implementations. Readers interested in complete JFET-based compressor circuit designs will be able to find many examples by searching online.

Use of audio limiters and compressors

Audio signals can vary very substantially in volume or loudness over time – the range of loudness (quietest to loudest) in an audio signal is called the dynamic range, and in some circumstances the dynamic range of the signal source is large enough to be problematical. Examples include situations where, if the quietest parts of the audio were at an acceptable level, then the loudest would be at dangerous levels to listeners or would cause excessive distortion in amplifiers and speakers. Similarly, in converting signals from analogue to digital the analogue-to-digital converter will have a fixed dynamic range (from the least-significant bit to the maximum digital code value), which may be smaller than the dynamic range of the source, again excessive distortion can occur if the converter's maximum input level is exceeded. Another situation where audio dynamics can be a problem is when switching between different sources (eg, different speakers in conversation) where some might be much louder than others due to differences in the signal processing in each case. This could be difficult to listen to even if the loudest source did not cause distortion.

Limiters and compressors can address these problems by reducing the dynamic range of the signal to avoid distortion and/or provide a safer or more comfortable listening experience. They can also be used in more specific ways; for example, in manipulating the sound from musical instruments. Compression of audio dynamic range can make audio sound louder, particularly when there is a hard limit on the maximum peak amplitude. Compression used in this way should not cause the maximum level to be exceeded (that would cause distortion) but allows the average level to be larger – so with everything else equal (no change of volume control) the perceived loudness increases. Record companies have increased compression of recorded music over the years to increase the perceived loudness of their product (this is known as the 'loudness wars'). Unfortunately, this is often detrimental to the quality of the music, where dynamics are usually an important part of a good listening experience. Similarly, the audio in adverts in many situations is often highly compressed and therefore sounds louder than other content.

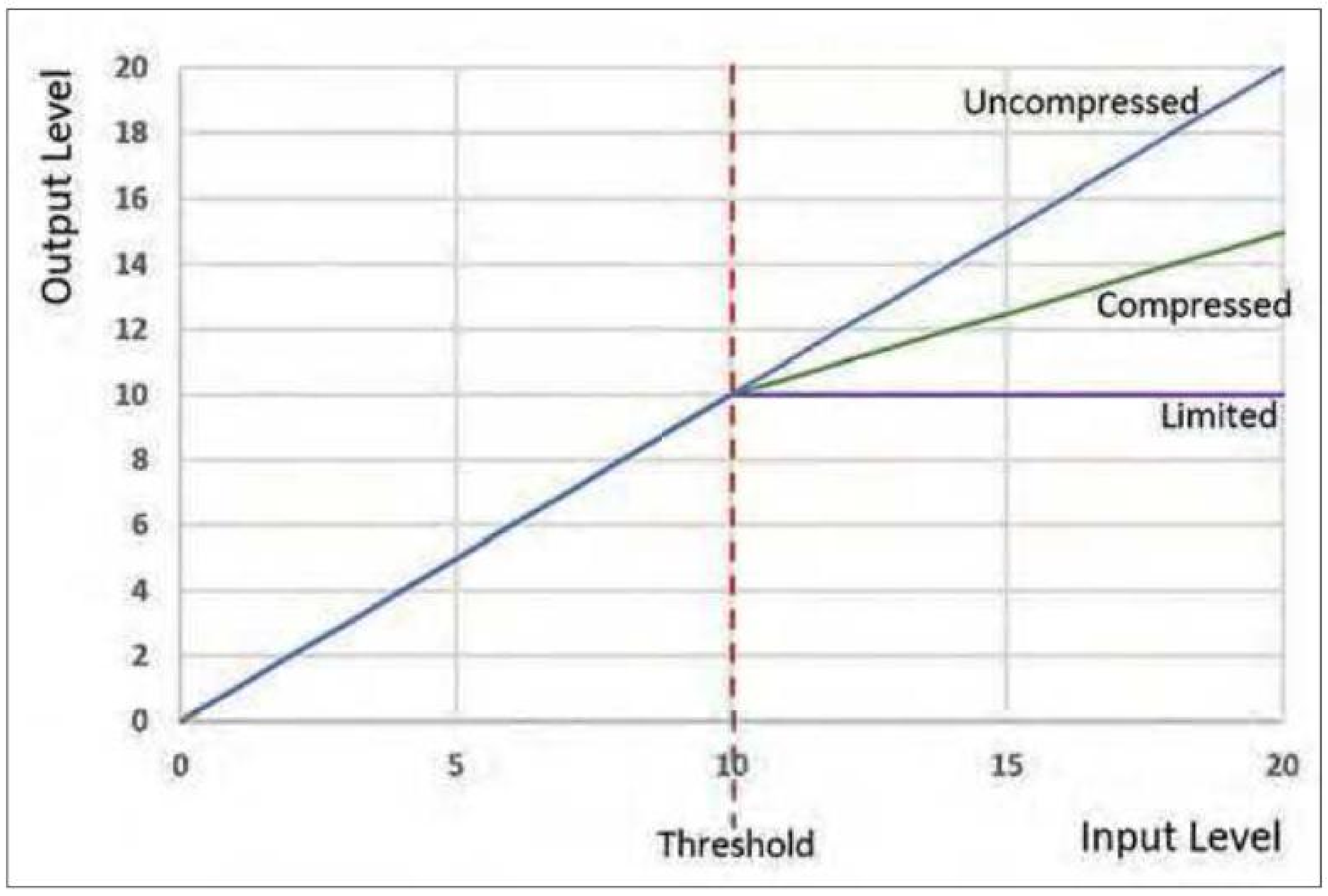


Fig.1. Relationship between input and output levels for uncompressed, compressed and limited signals.

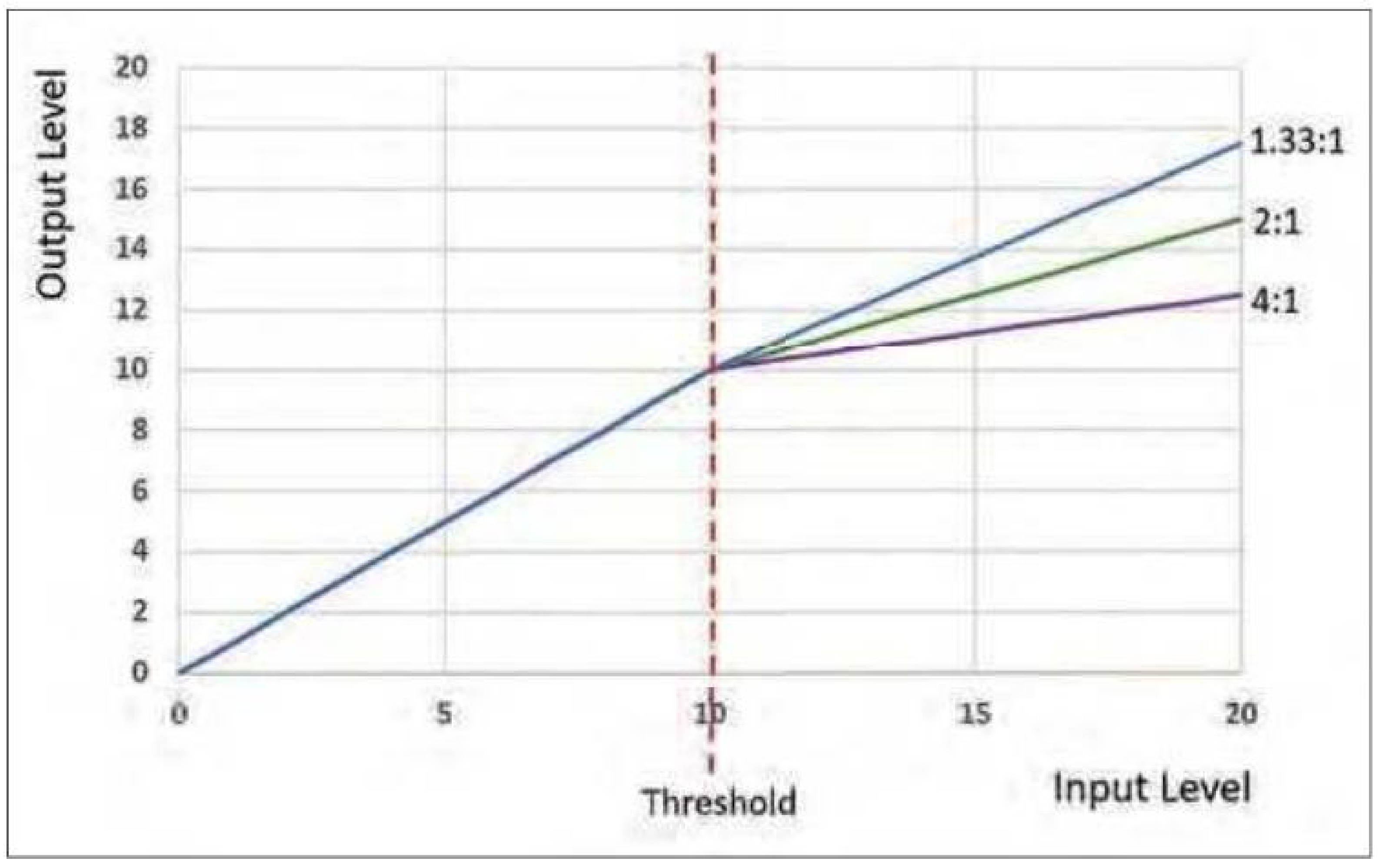


Fig.2. Examples of different compression ratios.

Compressor characteristics – threshold and ratio

The most common form of audio dynamic range compression does not affect the quietest signals but reduces the effective gain for louder signals. Thus, increasing the level of a loud signal input by the same relative change as a quiet input signal results in a smaller relative change in the output level for the loud signal. Limiting is an extreme case of compression in which increases in input level of loud signals do not cause any change in output level. The different processing of 'quiet' and 'loud' signals implies a threshold dividing the two. Fig.1 shows a plot of input level against output level for a compressor, limiter and uncompressed signal (standard amplifier). The levels are in arbitrary units (eg, could be decibels (dB) or volts) and show an uncompressed gain of 1, but the output values could be scaled to show non-unity gain or attenuation.

Before we go any further, an important terminology point. From the above you can see that the word 'threshold' is used with two distinct meanings in the context of a JFET-based compressor. A JFET's threshold or threshold voltage is the minimum gate-to-source voltage ($V_{GS(th)}$ or V_T) that is needed to create a conducting path between the source and drain terminals. The compressor's threshold is as described in the previous paragraph. In the following, assume unless specifically indicated otherwise that when the word 'threshold' is used it is referring to compressor action.

The amount of compression is expressed as the compression ratio – this is the ratio between the level above the threshold for an uncompressed signal and the level above the threshold for the compressed signal. The ratio is 1:1 for uncompressed and ∞:1 for an ideal limiter. Fig.2 shows some compression ratios between these extremes. Real limiters do not need to have an ∞:1 ratio – tens to one is sufficient. As a limiter is a special case of a compressor, we will just use the term compressor from now on.

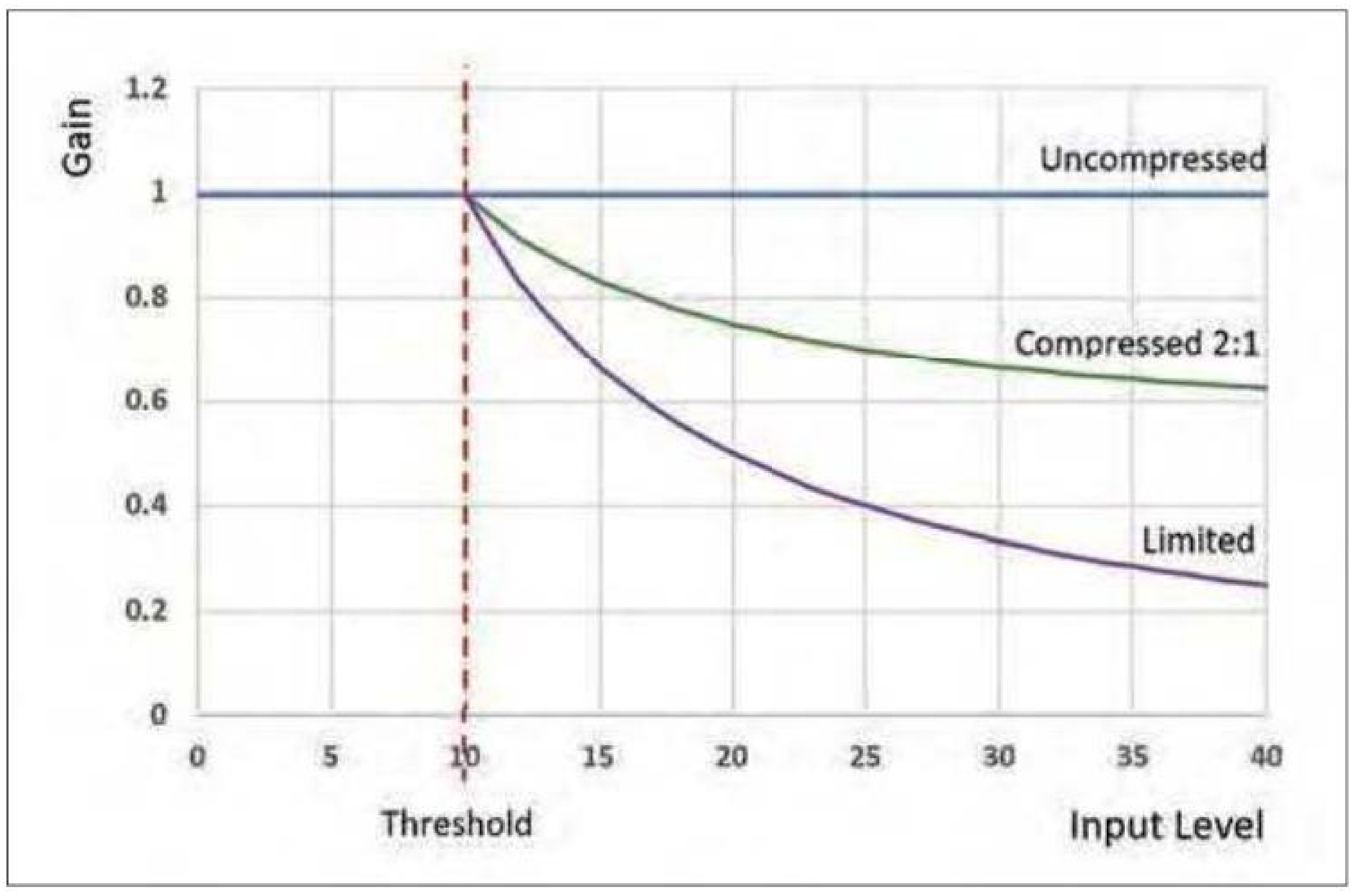


Fig.3. Gain of compressor against input level.

To reduce the output level with respect to the uncompressed output, a compressor must reduce its gain as the input level increases above the threshold. The gain values for the cases shown in Fig.1 are shown in Fig.3, with an extended input level range to better see the shape of the curves. The uncompressed response has a constant gain for all input levels. The compressed and limited responses have constant gain below the threshold. Above the threshold the compressor gain decreases – the shape of the curve is a reciprocal function (related to one over the input level) and is asymptotic to $1/R$ for a compression ratio of R:1. For example in Fig.3 the 2:1 compressed curve will level off at 0.5 (=1/2) for very large input levels and the limiter gain will eventually level off at zero (=1/∞).

Compressor timing – attack and release

The 'level' values in Fig.1 and Fig.2 are the average level of the signal over time, not the instantaneous level of each peak in the signal waveform. Audio signals such as speech and music have complex waveforms with successive peaks at different levels, and if a compressor changed its gain with each peak the waveform would be badly corrupted. Consider an audio input where there was a sudden increase in volume level – anything observing the signal would not know during the first few waveform cycles after this if the signal was just exhibiting a few particularly large peaks or if there was a significant change in average level. Compressors therefore respond by slowly increasing or decreasing their gain for step changes in level above threshold.

The speed of response may be different for increases and decreases in level, so we have two parameters which define the speed of response. The attack time is the period taken to respond to an increase in average input level and the release time is the time taken to respond to a decrease in average input level. These times are typically in the range units to hundreds of milliseconds and may have a significant effect on the perceived audio quality of the output. Different values may be used depending on the type of audio being processed and the context of it use.

Fig.4 shows a typical compressor waveforms for a signal with a step change in input level. The input starts below the threshold but then increases quickly to a level above threshold (see top trace). The gain of the compressor (gain control signal in Fig.4) will decrease to reduce the gain for the larger input signal. It takes the attack time for the change to the lower gain to fully take place. After some time at the larger amplitude, the input in Fig.4 drops quickly back to the initial lower level. The gain therefore increases back to the original level. Again, this does not occur instantaneously, and in this example the time to return to the higher gain (release time) is longer than

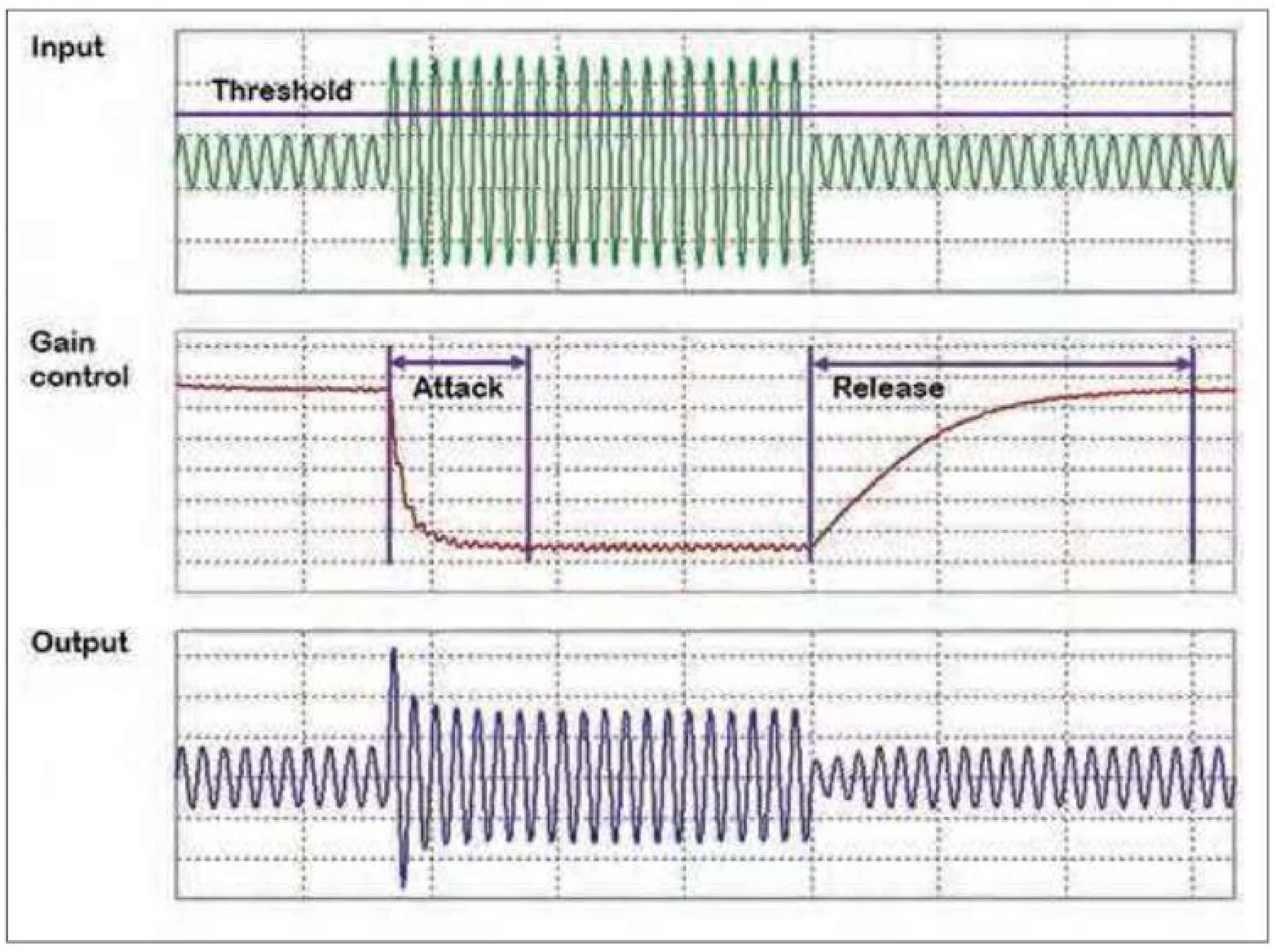


Fig.4. Example compressor attack and release times.

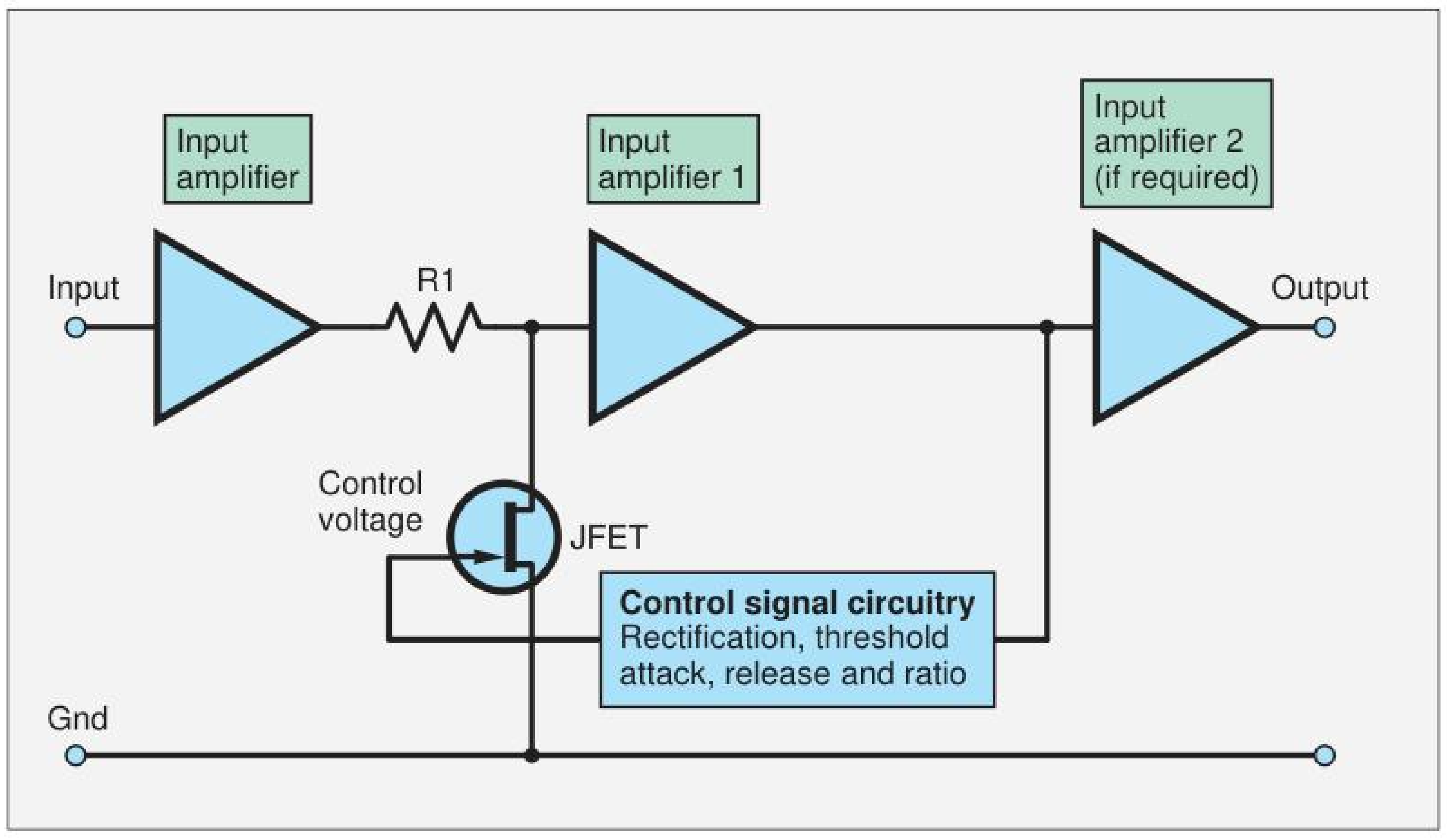


Fig.5. Simplified block diagram of compressor circuit using JFET attenuator to control gain.

the attack time (which is typical). In Fig.4 it can be seen that the relative change in the output level due to the step change is smaller than the relative change in input level due to the action of the compressor.

JFET compressor circuit

Fig.5 shows a simplified block diagram of an audio dynamic range compressor or limiter based on the JFET voltage-controlled attenuator/amplifier circuits discussed last month. To minimise distortion, feedback of 50% of the JFET drain-source signal would usually be applied to the JFET gate, but this is omitted from Fig.5 to simplify the diagram. The feedback can be applied directly around the JFET or from one of the amplifiers connected to the potential divider output, as discussed last month.

The circuit in Fig.5 operates as follows. The input signal is amplified (or attenuated) by the input amplifier, which provides high input impedance to prevent the JFET potential divider attenuator loading the signal source. It, together with the choice of R1, also ensures that the voltage levels applied to the JFET are appropriate (the drain-source voltage must be small for low distortion – as discussed in the previous articles).

The signal from the input amplifier is attenuated by a variable amount by the potential divider formed by R1 and the JFET. The amount of attenuation (and hence overall gain when the output amplifiers connected to the potential divider are considered) is set by the control voltage applied to the JFET gate. This is the same principle as the variable gain amplifier discussed last month. Here the control voltage is derived from the level of the output signal – thus the circuit has a feedback loop which can reduce circuit gain as signal level increases in order to achieve the compression or limiting function discussed above. The second output amplifier may be needed if the signal level from the first amplifier is not equal to the required final output or if buffering is required.

As discussed above, the gain control is based on the average signal level over time and needs to respond at a suitable speed (the attack and release times defined above). This can be achieved by rectifying and filtering the signal from output amplifier 1 and applying it to an *RC* filter (which sets the response times). This is the same basic principle as the circuits used in simple AM radio detection and AC-to-DC power supplies. The simplest version of this is shown in Fig.6, but typically real compressor designs will use more sophisticated circuits. In particular, Fig.6 is only a half-wave rectifier, but a full-wave rectifier should be used. Usually this would be implemented using an op amp-based precision rectifier, which avoids errors due to diode voltage drops. The op amp rectifier can also act as output amplifier 1. In principle, even better performance can be achieved by using a circuit to obtain a true RMS (root mean square) average value for the audio signal.

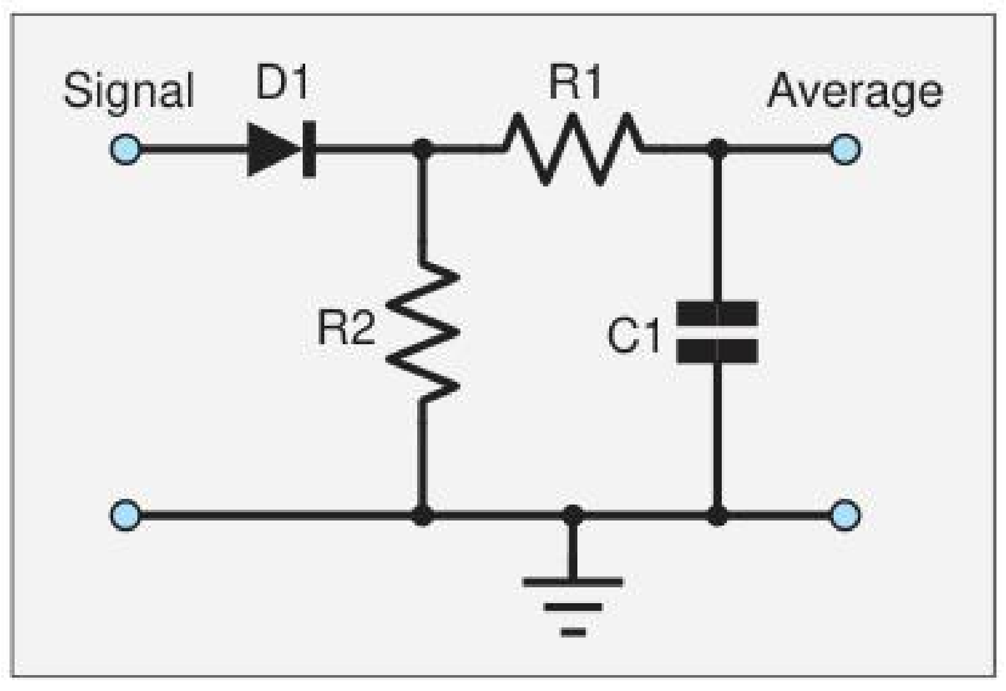


Fig.6. Very basic circuit for obtaining average signal level with control of attack and release times.

In Fig.6, the attack time is controlled by the *RC* time constant of R1 and C1. If R2 was not present C1 would charge up to a value related to the maximum signal level and never decrease (expect due to leakage). R2 discharges C1 and ensures that the average circuit output decreases when the average input signal level decreases. Since the discharge path for C1 is via both R1 and R2, their combined value (along with C1) sets the release time. R2 is connected as shown, rather than directly across C1 to avoid forming a potential divide for the rectifier output.

The JEFT in Fig.5 will switch off with relatively large negative voltages at the gate. Under these conditions it is effectively open circuit and the JFET-plus-R1 potential divider will have a gain of one. As the control voltage increases (becomes less negative) the gate will reach the JFETs threshold voltage, the device will turn on, its resistance will decrease and the signal will be attenuated. Further increases in control voltage (towards 0V) will decrease the gain. If the circuit is set up with appropriate bias/reference voltages and signal levels the JFETs threshold can be mapped to the compressor threshold.

JFET gain-control characteristics

We can run some simulations to illustrate that the JFET potential divider characteristics can match the requirements for gain control of the compressor shown in Fig.3. In the first article we showed graphs of the variation of JFET resistance with gate-source voltage, and noted that it was non-linear, but did not discuss further details. To be more specific now, the relationship between the JFET's drain-source resistance (R_{DS}) and the gate-source voltage (V_{GS}) at small drain-source voltages is given by:

$$R_{DS} = \frac{A}{(V_{GS} - V_T)}$$

Here, A is a constant dependent on device construction and V_T is the JFET's threshold voltage (typically around –3V for an n-channel JFET). A key thing to note here is the resistance is inversely proportional to the gate-source voltage above the JFET's threshold. Thus, applying a control voltage to the JFET in the potential divider (in Fig.5) that is proportional to signal amplitude will result in a gain of the potential-divider-plus-amplifier which

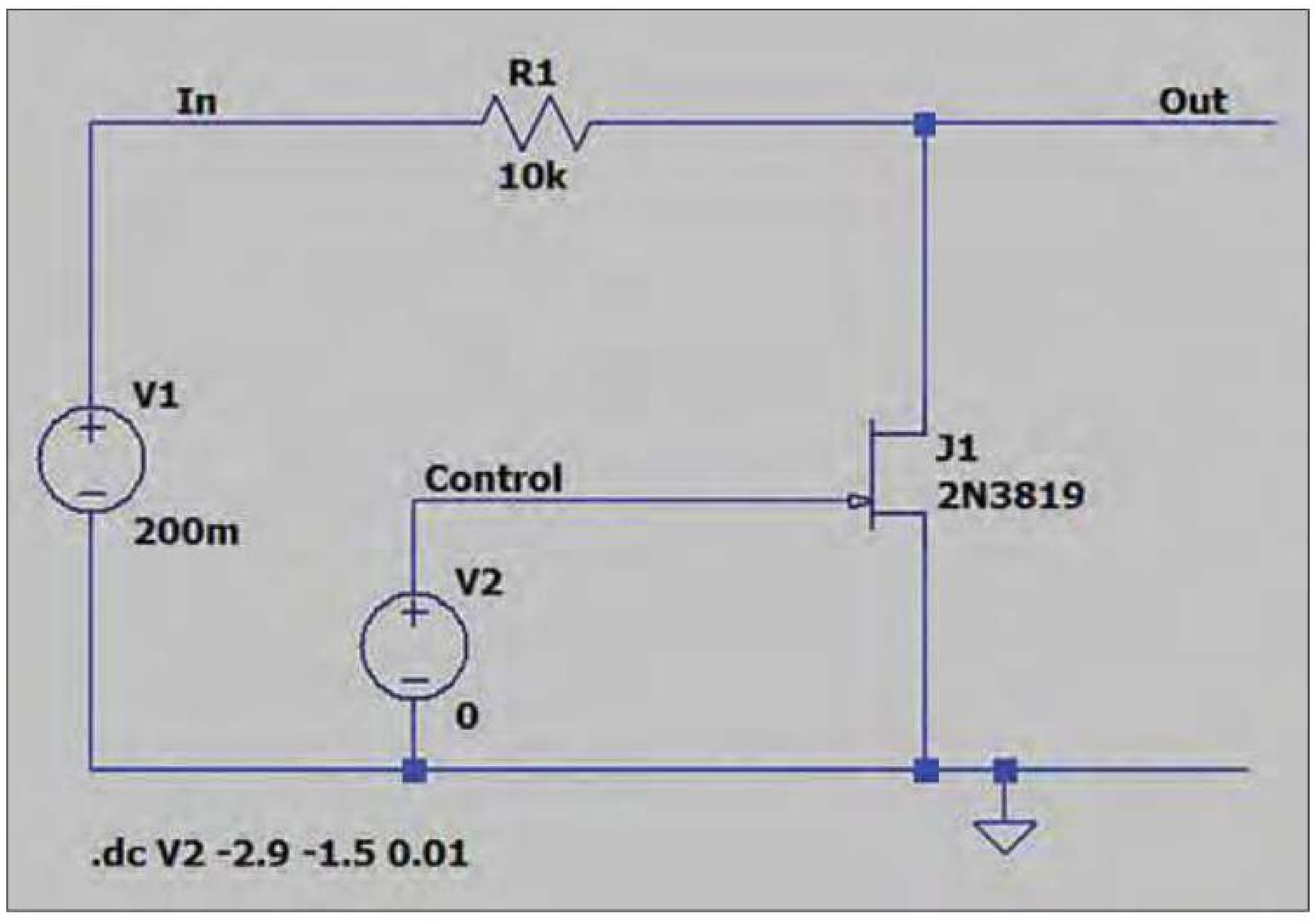


Fig.7. LTspice circuit to investigate JFET resistance and potential divider gain.

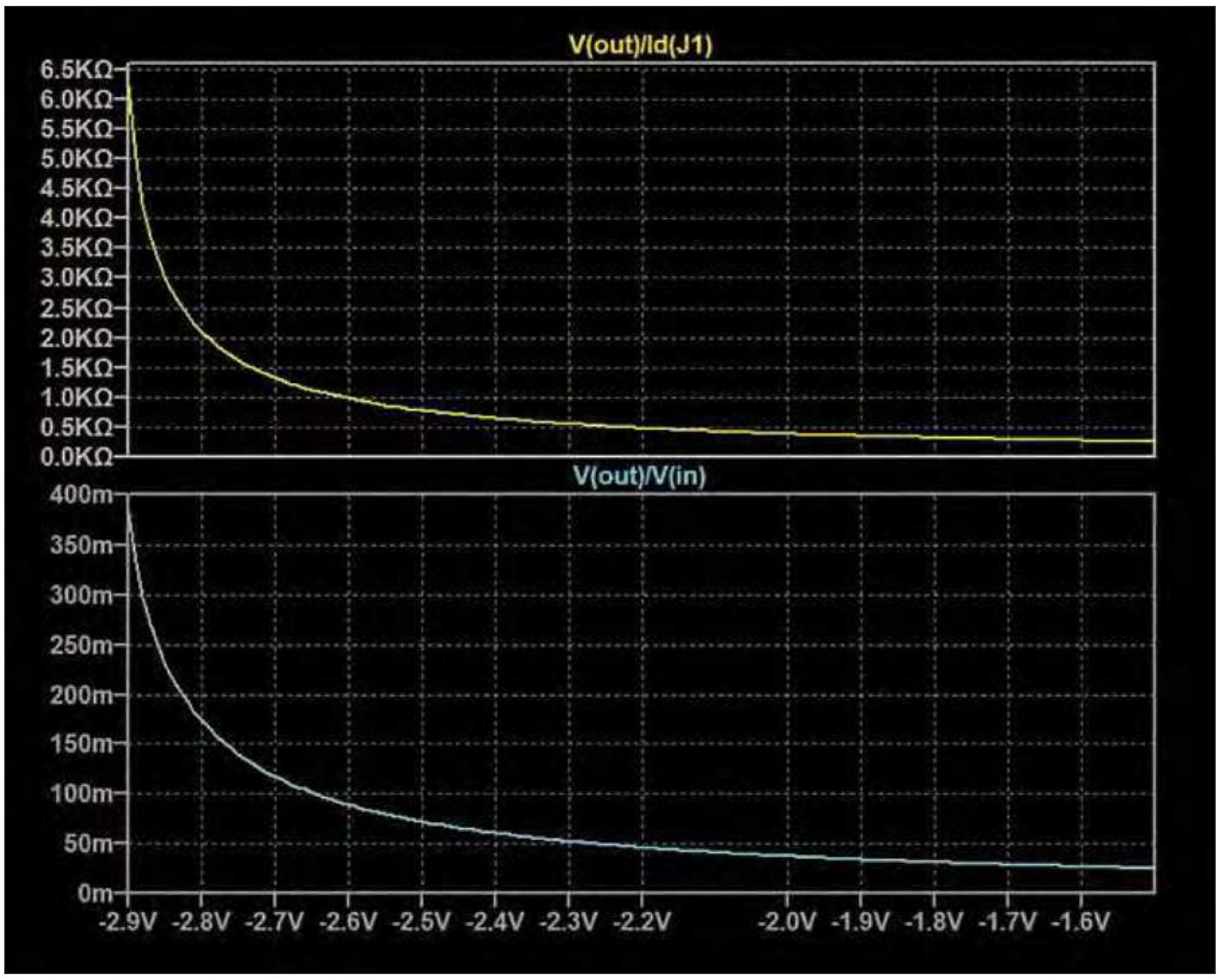


Fig.8. Simulation results for the circuit in Fig.7 (JFET resistance top and potential divider gain bottom).

is inversely proportional to the signal amplitude – which is the relationship we see in Fig.3 above the compression threshold. Furthermore, if the circuit is configured correctly, low average signal amplitudes will produce a control voltage below the JFET's threshold and hence a constant gain.

Simulations

Fig.7 shows an LTspice schematic which can be used to illustrate the JFET resistance and potential divider gain-to-gate-source voltage relationship discussed above. The circuit applies a constant 200mV DC voltage to the R1-JFET potential divider and uses a DC sweep simulation to plot the response of the circuit for V_{GS} values ranging from −2.9V to −1.5V. The sweep range starts at −2.9V as this is just above the JFET's threshold voltage (V_T) of the 2N3819, which is −3V in the LTspice model. The results are shown in Fig.8. The top trace shows the resistance of the JFET (calculated using drain-source voltage (equals `V(out)`) divided by drain-source current (`Id(J1)`). The lower trace shows the gain of the potential divider (`Vout/V(in)`). We can see the reciprocal relationship between both the JFET resistance and the potential divider gain, and the gate-source voltage above V_T.

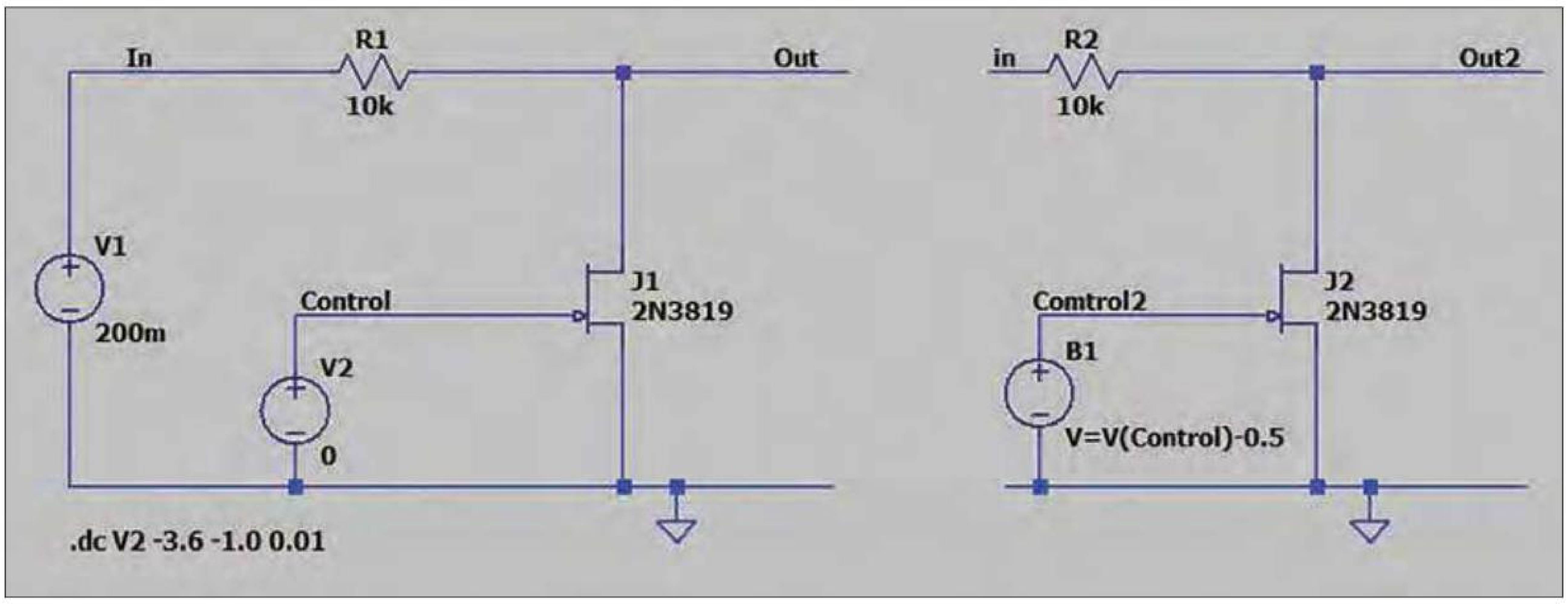


Fig.9. LTspice circuit to investigate JFET potential divider gain with respect to compressor gain control requirements.

The LTspice circuit in Fig.9 has two versions of the circuit in Fig.7. One is basically the same as in Fig.7 and the other uses a behavioural source to offset the control voltage (JFET V_{GS}) by 0.5V with respect to the first. The sweep range is extended with respect to Fig.7 to start below the JFET threshold voltage.

The results for Fig.9 are shown in Fig.10. The top plot simply shows the control voltages to confirm the 0.5V offset between them. The lower plot shows the potential divider gain for the two circuits. The shape of the curve is very similar to Fig.3 and shows that if we apply a control voltage to the JFET potential divider which is proportional to the signal amplitude and mapped onto a range appropriate for the JFET, then we achieve the gain variation characteristics required by a compressor

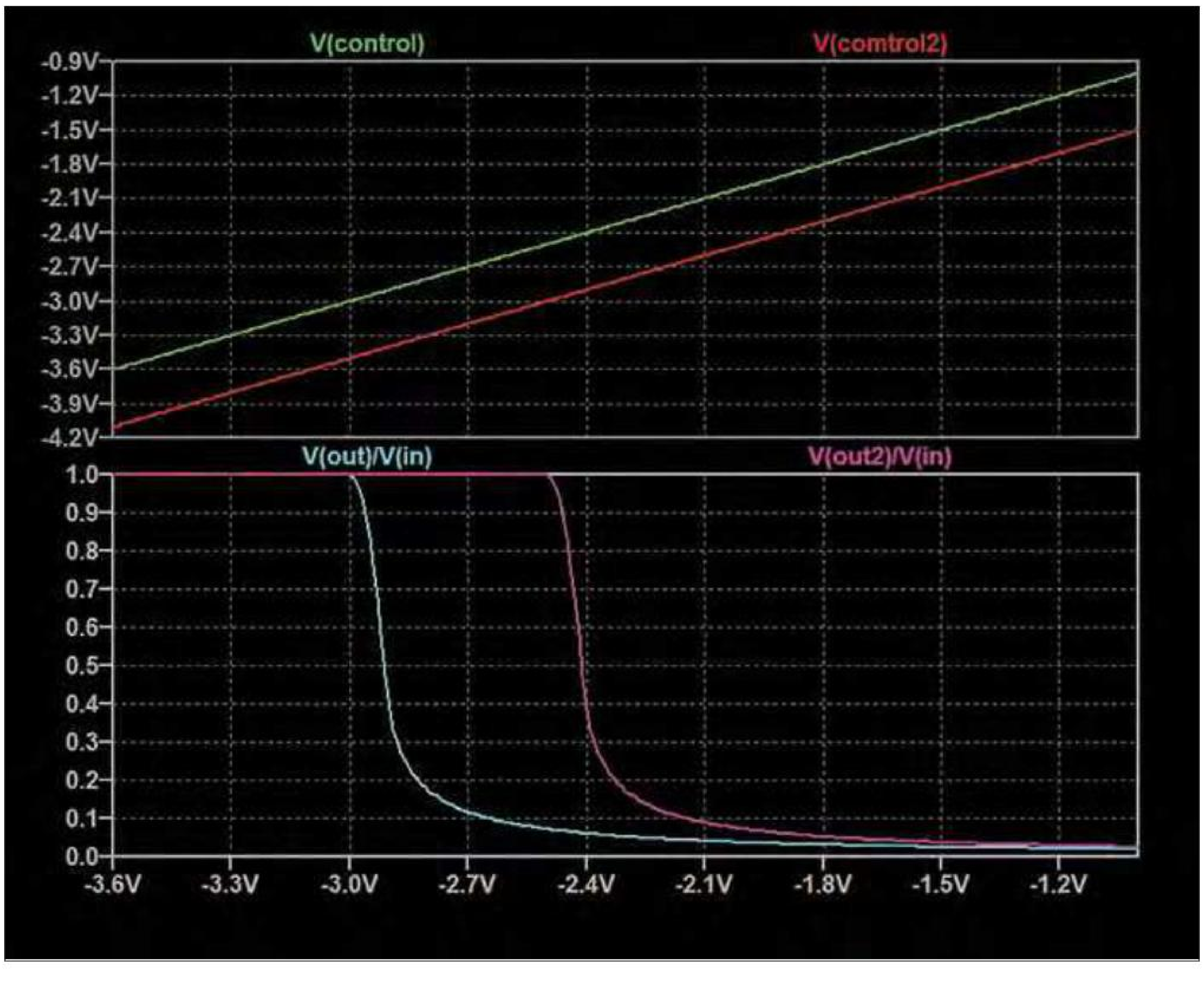


Fig.10. Simulation results for the LTspice circuit in Fig.9.

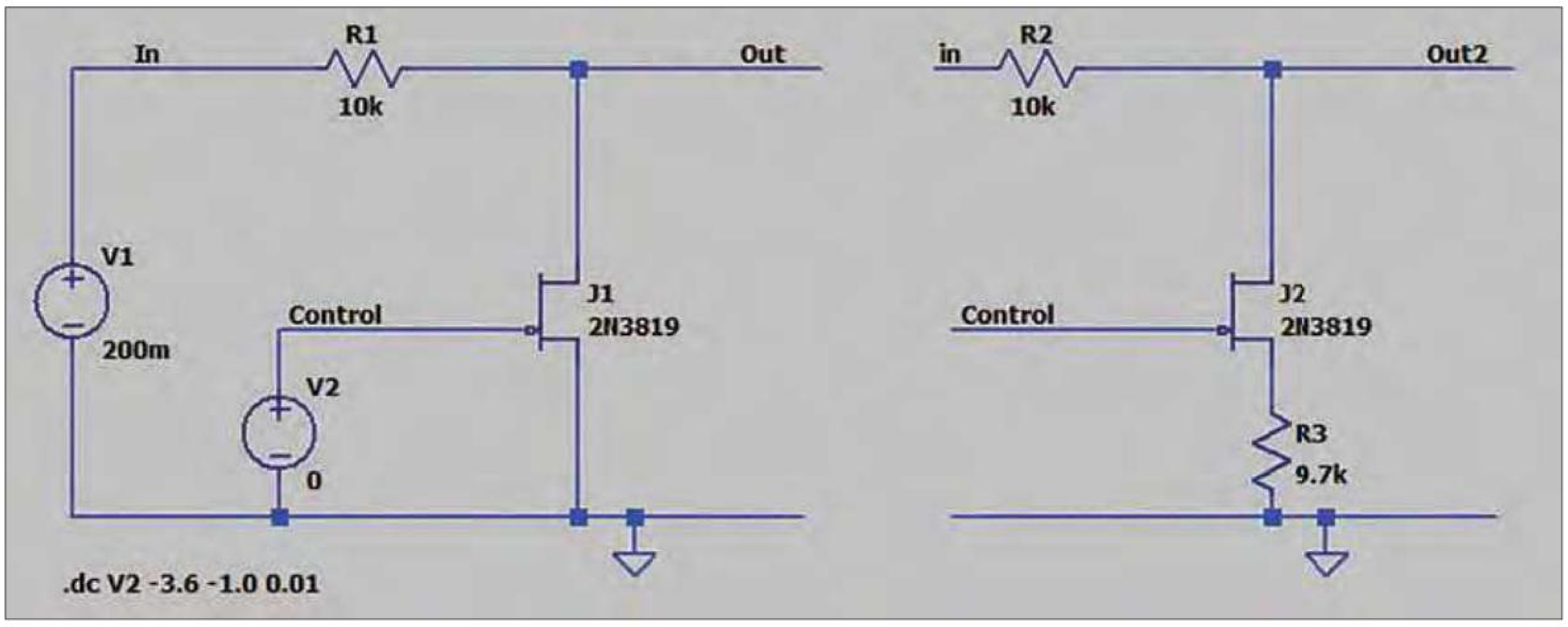


Fig.11. Another LTspice circuit to investigate JFET potential divider gain with respect to compressor gain control requirements.

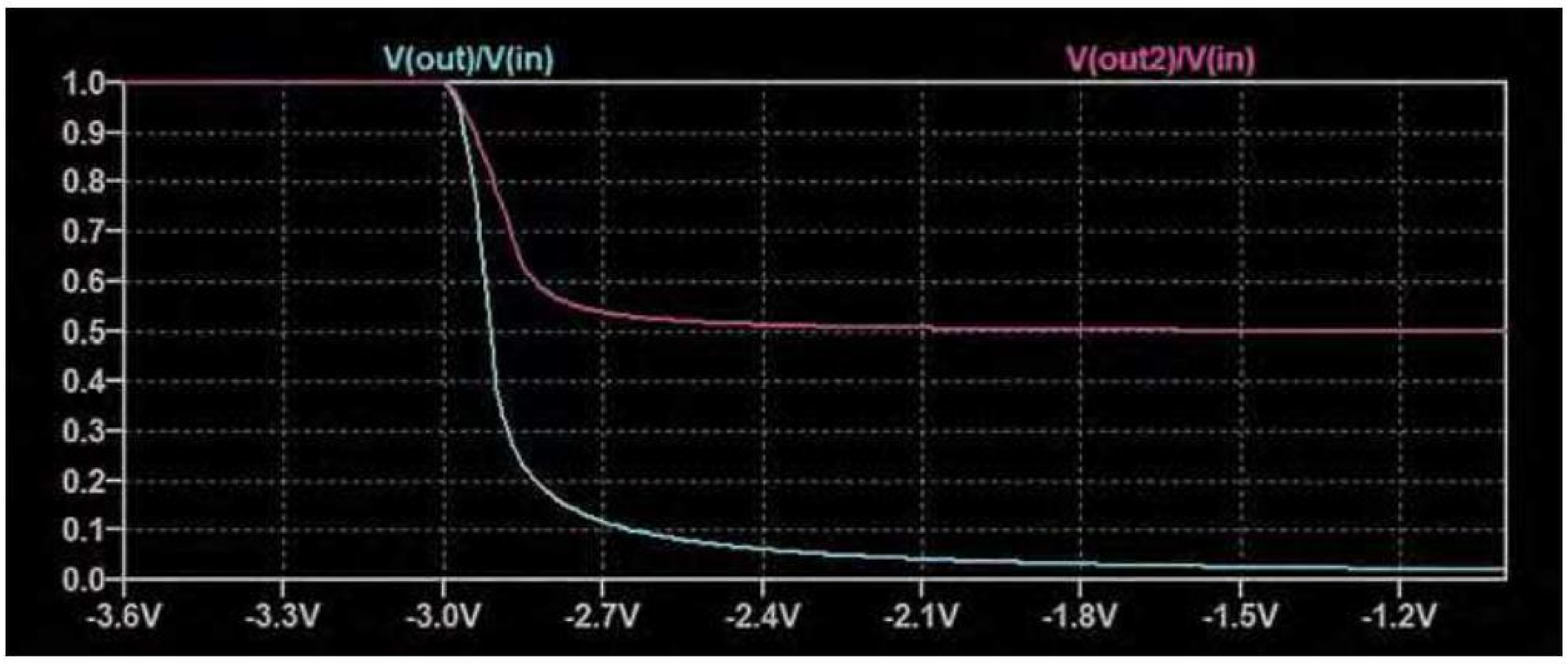


Fig.12. Simulation results for the circuit in Fig.11.

circuit. By changing the DC offset of the control voltage, we can modify the compressor threshold.

We can manipulate the characteristics of the JFET potential divider by adding additional resistors. This is illustrated with LTspice using the circuit in Fig.11 where a resistor has been added at the JFET's source. This resistor will change the limit of the potential divider gain when the JFET resistance is small. The results are shown in Fig.12. Comparing FIg.12's plots with Fig.3, we see can the source resistor could be used modify the compression ratio.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*. The examples and files are available for download from the *PE* website.

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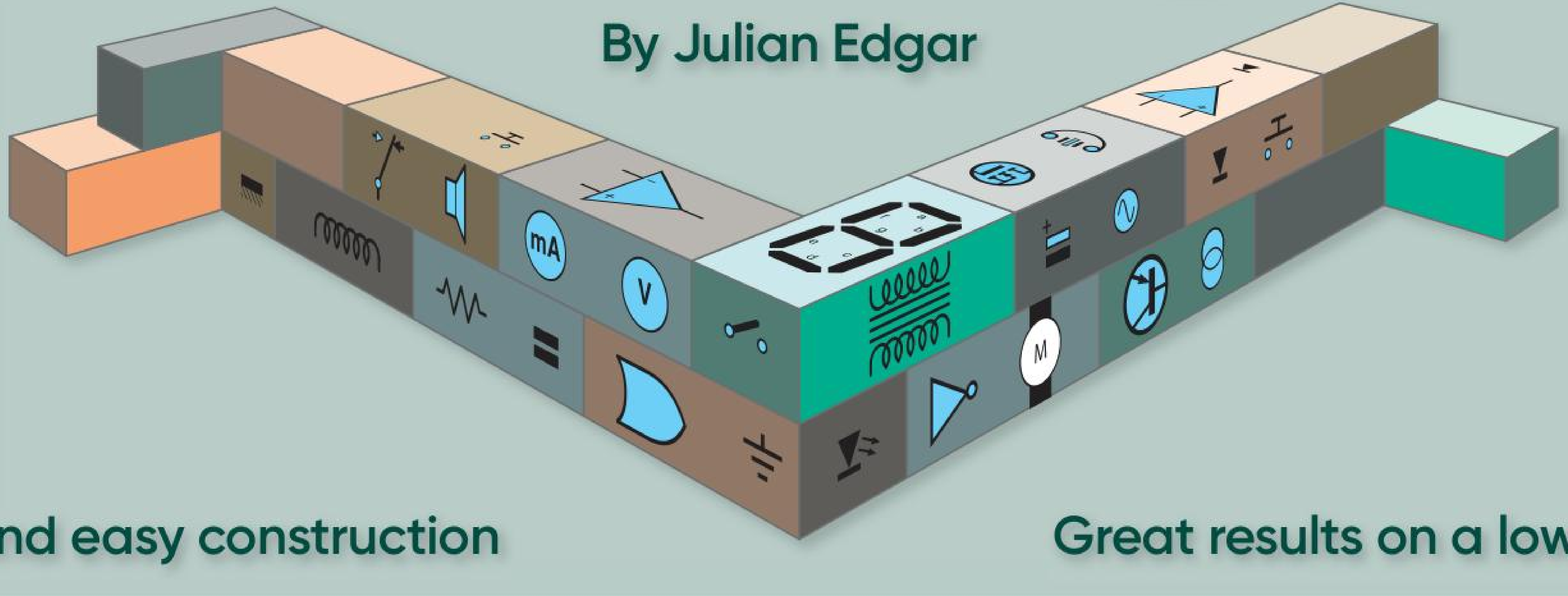

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Selecting and Using Actuators – Part 2

Turning electronic signals into physical movement – linear and rotary

Last month, we looked at some of the ways that we can turn electronic signals into physical movement. We covered DC motors and their use in linear actuators and RC servos. This month, we continue with gear and stepper motors.

Gearmotors

Gearmotors are small DC motors that have a gearbox mounted on one end. The gearbox reduces motor speed and increases torque, making the motors useful in a wide range of applications where continuous rotation is required. Most of these motors use a D-shaped output shaft, so pulleys and wheels with a suitable female opening can be connected, with or without set-screws (Fig.1).

Micro metal gearmotors use a small motor (10 x 12mm cross-section) and exposed reduction gears. They are available in a very wide range of gearing – from 5:1 to 1000:1. ‘20D’ gearmotors use enclosed gearboxes, with the assembly 20mm in diameter. Available ratios are from 29:1 to 154:1. Still more gearmotors are available in 25mm and 37mm diameters with a wide variety of gear ratios.

If you intend operating a gearmotor for long periods, ensure that you select one equipped with carbon brushes – some use precious metal brushes that wear more quickly. Literally hundreds of configurations of these motors are available, with varying gear reductions, output shaft lengths and configurations (eg, right-angles), stall currents and supply voltages. Output torque values can be over 50kg-cm.

Some motors are available with quadrature encoders (eg, up to 64 counts per rotation) giving feedback of motor speed and/or direction.

If you intend using a gearmotor in a common application (eg, turning a wheel on a model car or robot) then the cheapest approach is to buy a kit that comprises the motor, wheel, coupling and mounting bracket (Fig.2).

If you are after a large and powerful gearmotor, and are working to a strict budget, salvage a battery-powered electric drill. (The drills using old battery technology – eg, nickel-metal hydride (NiMH or Ni–MH) batteries – are very often discarded.) Inside, you’ll find a brushed DC motor connected to an epicyclic gearbox (Fig.3). The assembly is easily removed and connecting it mechanically to the output is easy – you just clamp a shaft in the chuck. These motor/gearbox assemblies produce excellent torque, even at low supply voltages, thus allowing them to be speed controlled over a wide range while still having the grunt to operate real-world loads. The clutch

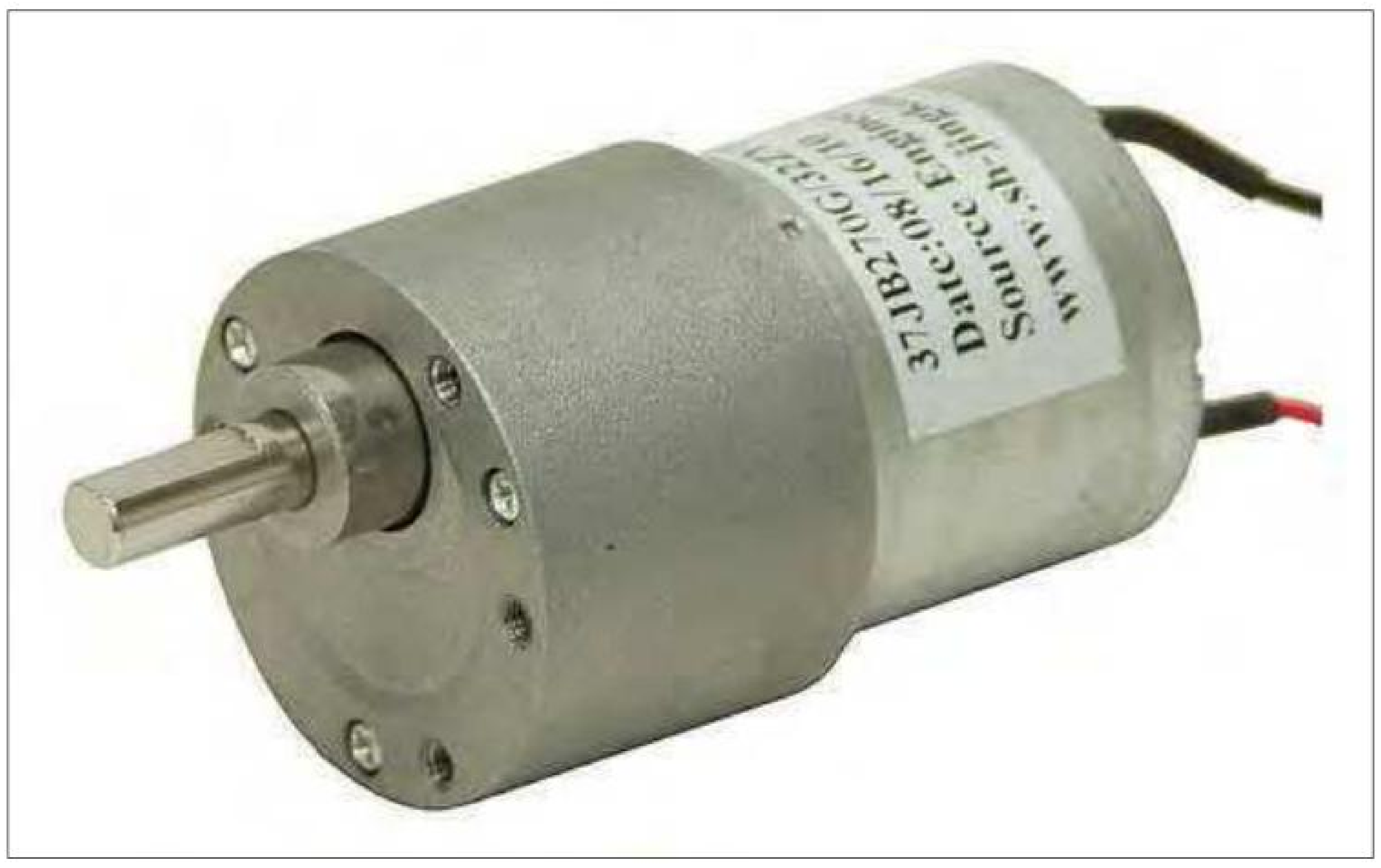


Fig.1. A gearmotor – note how the gearbox is attached directly to the end of the motor, giving a compact assembly. The typical D-shaped output shaft can be seen. This gearmotor is a 24V design that rotates at a no-load 25 RPM (150°/s). Cost is just £6.

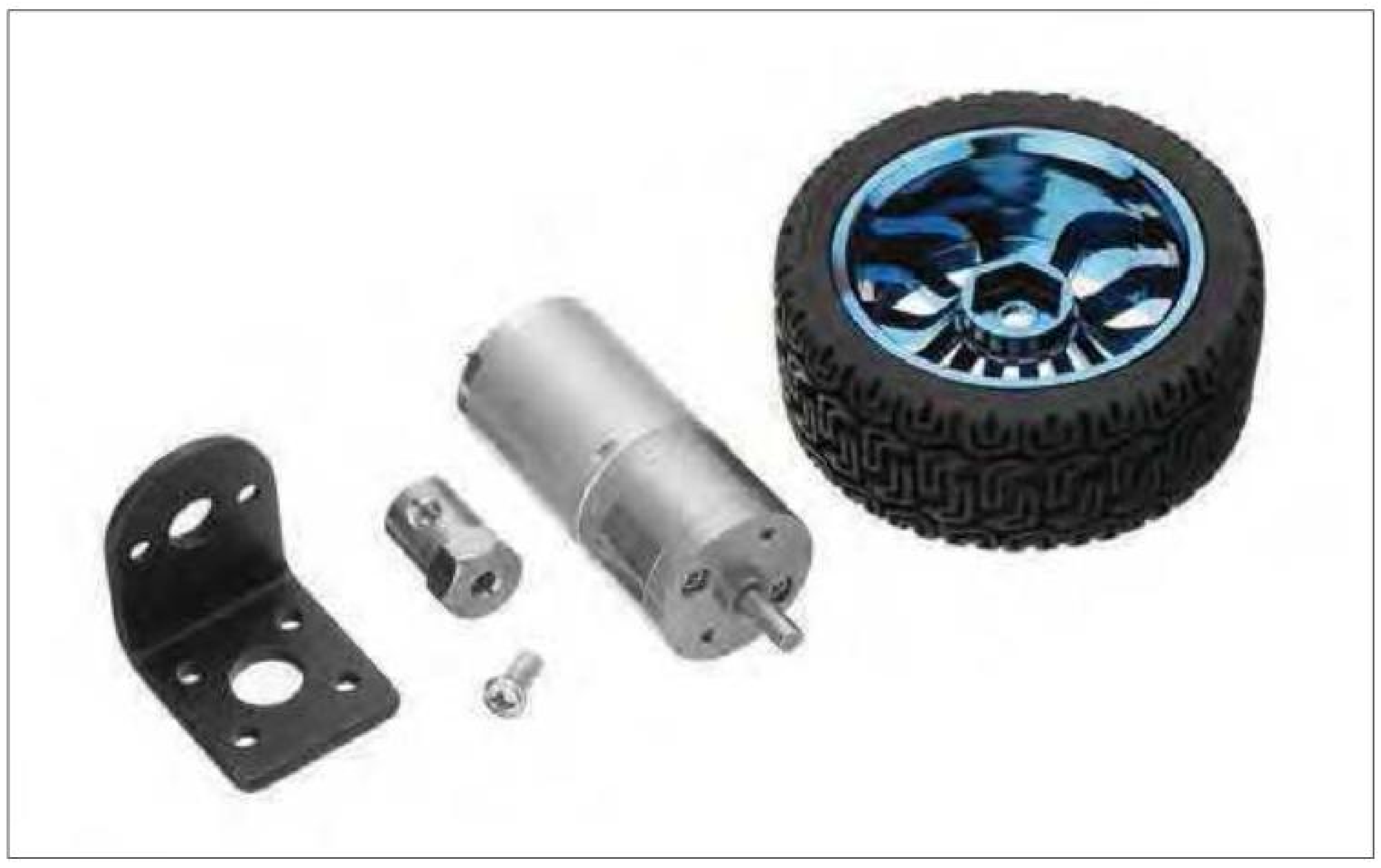


Fig.2. A gearmotor, mounting bracket, coupling and wheel. Gearmotors are ideal for driving wheels on moving robots and similar – this gearmotor operates on 6V, draws a loaded 0.5A and rotates at 100 RPM. Cost is £11. (Courtesy Banggood)

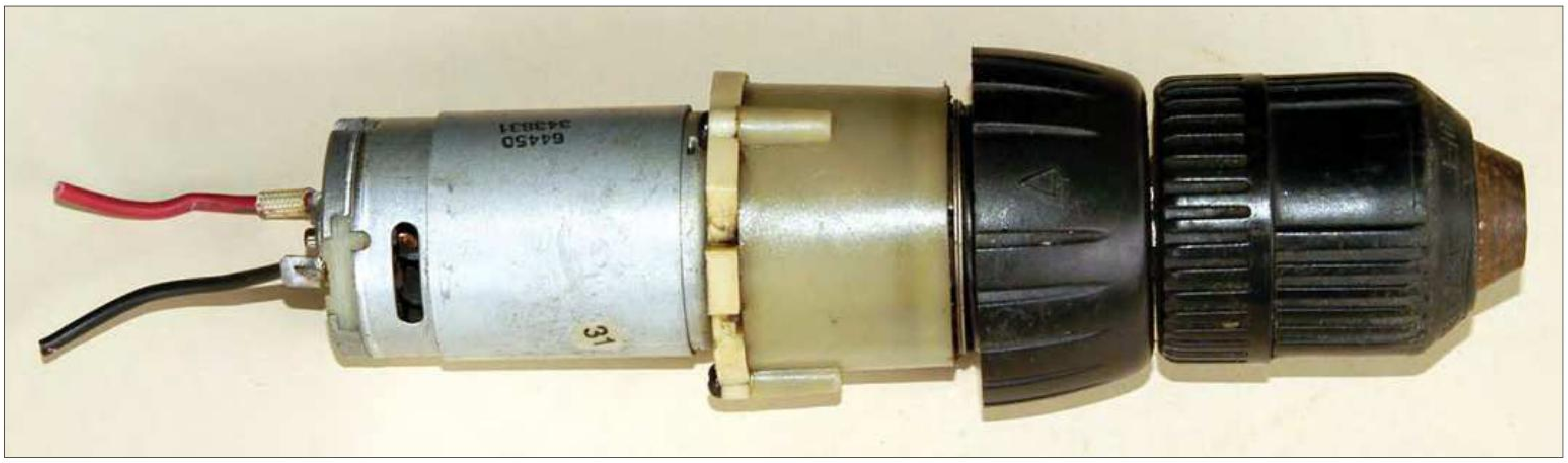


Fig.3. The motor/gearbox assembly from an old battery-powered electric drill. These can be obtained at low/no cost and have excellent torque. The mechanical connection to the output can be made by clamping a shaft in the chuck.

fitted to many drills can even be used to protect the motor should the load stall.

In summary, where continuous, high-torque rotation is needed, a gearmotor is an excellent choice. The huge range and ready availability of couplers, mounts and accessories also means that you can assemble lots of different projects without any machining or complex metalwork. However, keep in mind that gearmotors are not 'commercially rated' – ball bearings are not used and there is no facility for easily oiling motors and gearboxes.

Stepper motors

In contrast to the continuous rotation achieved by DC brushed motors, stepper motors – as the name suggests – are driven in discrete steps, each step being a small or very small fixed fraction of a full rotation. Stepper motors are used in professional and hobby 3D printers and CNC machines designed to machine wood, plastic or metal. They're also used in printers, cameras and many other consumer and industrial goods – see Fig.5.

Stepper motors have three major advantages over other actuators. The first is that because they can be driven in discrete steps, the position of the output shaft can be determined with accuracy. That is, if the output shaft is rotated by – say – 50 steps, because the angular rotation is known for each step, the final shaft position can be accurately determined. (Note, though, that this is open-loop control – there is no position feedback built into a stepper motor. To cater for this, most commercial users of stepper motors have systems where a variable being influenced by the action of the stepper motor is separately monitored, or something like a microswitch is used to establish a 'start' position on a repetitive basis.)

The second major advantage is that a stepper motor has good low-speed torque. It can therefore get loads moving from a standstill better than most other actuators, without needing gearing. Finally, a stepper can be speed-controlled accurately – the electronic controller determines the required number of steps per second; making it essentially a frequency-based controller.

While stepper motors are most often used in applications where position or speed are important, in many hobbyist applications stepper motors are also useful when an ultra-durable motor is required. Most medium and large stepper motors are equipped with ball bearings (rather than plain bearings), and don't need commutator brushes, which wear

Fully opened and closed automatic switch-off

Actuator position feedback can quickly get quite complex. Usually, a microcontroller is needed – and it will typically need to run PID software to do a good job. But what if you simply want a DC motor to turn off when a certain position is reached? In that case, you can use the approach taken in linear actuators. Let's look at this more closely – it's elegant and simple.

Let's imagine we want to turn off an actuator when a door is fully opened or closed. Two normally closed (NC) series microswitches are used in the power feed to the actuator motor, with their levers or buttons arranged so that one switch is opened when the door is fully open, and the other switch is opened when the door is fully closed. Across each microswitch is wired a parallel diode, oriented cathode to cathode.

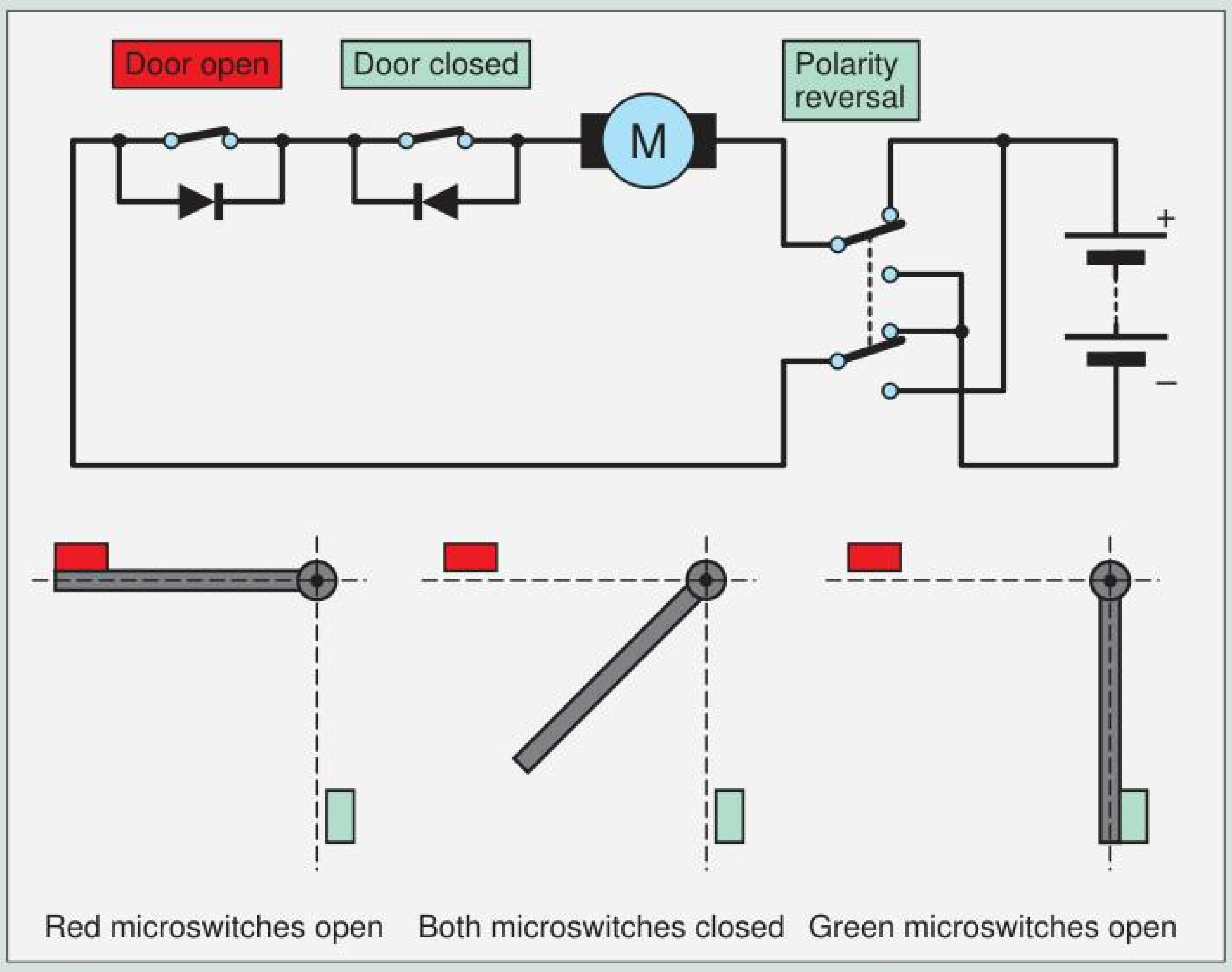


Fig.4. An easy way to automatically switch off a DC motor's power in 'fully opened' and 'fully closed' positions.

When you want to open the door, you feed power to the circuit. Then, when the door has fully opened, the microswitch cuts off power to the motor. When you wish to close the door, simply swap the polarity of the motor feed. The diode associated with the 'door open' microswitch will allow the current to bypass the switch, so causing the actuator to move in reverse. When the door fully closes, the same thing happens, but this time it's the 'door closed' switch that opens to stop power. Note that the diodes must be rated for the current requirement of the motor.

Fig.5. Stepper motors are used in a very wide variety of consumer and industrial equipment, making salvaging second-hand steppers easy. They're also available new from many sources. (Courtesy Adafruit)

out, thus they are reliable and have a long life. If you need a motor to turn continuously, using a stepper motor may well be a better approach than using a conventional brushed DC motor.

However, stepper motors have a significant downside – to achieve all these good things, sophisticated electronic control is needed. And, unlike servos, the controller needs to be able to handle the current demand of the stepper motor. Further, to get the best results, the controller needs to be well matched to the specific stepper motor.

Stepper motors are available in wide range of sizes and configurations – from those as small as a coin to ones as large (or bigger than) as a coffee mug. However, many hobbyists use stepper motors that fall within the NEMA (National Electrical Manufacturers Association) frame sizing. NEMA sizing refers to the distance between the mounting holes, measured in inches. So, a NEMA 14 stepper motor has a distance of 1.4 inches between its flange mounting holes, a NEMA 17 has a distance of 1.7 inches between mounting holes, and so on. (Fig.6).

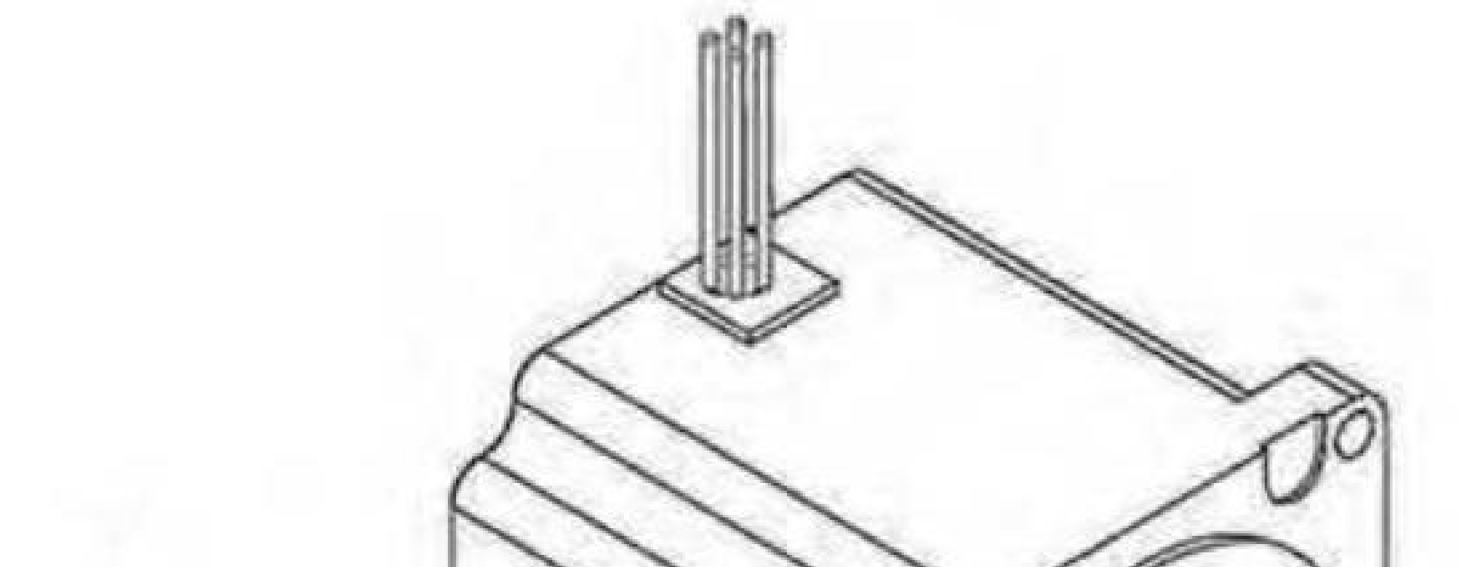


Fig.6. The NEMA standard sizes for a variety of stepper motors. Note that the NEMA spec applies only to the spacing of the flange mounting holes, not to the electrical specifications.

Note that the NEMA sizing refers only to the physical faceplate size – it doesn't refer to the mechanical or electrical characteristics of the motor. Having said that, NEMA 17 is commonly used in 3D printers and smaller CNC machines. The larger NEMA sizes are more common in CNC machines used in industrial applications. At the other end of the scale, tiny stepper motors are useful in robotic and animatronic applications.

Like gearmotors, stepper motors are available with D-shaped output shafts and there are lots of adaptors, shaft connectors, gears and levers available to help make the mechanical construction of a project more straightforward.

The next stepper motor specification to consider is the number of steps per full revolution. This can be expressed directly

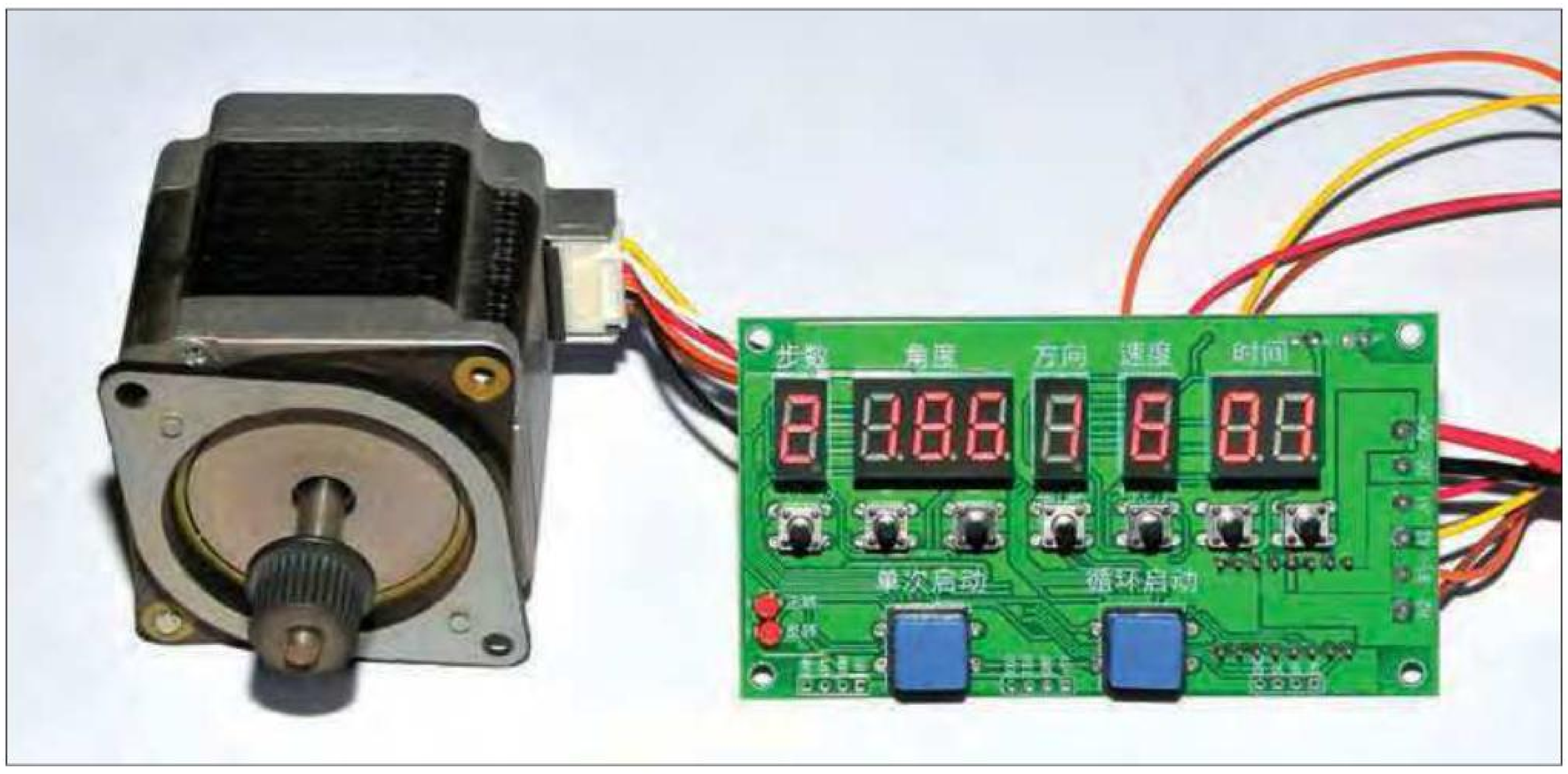


Fig.7 This standalone programmable controller is a very easy way of getting a stepper motor up and running. Speed, direction and rotational angle can all be set, and the module has the ability to store nine programs that can be run automatically in sequence.

in step count (eg, 200 steps/revolution) or indirectly as the degree of rotational change for each step – so 1.8° in this case. (360° / 200 steps = 1.8° per step.) Common step counts are 24, 48 and 200. Other stepper motor specifications include voltage, current draw per phase and holding torque. For example, a NEMA-17-size stepper may have the following specs: 1.7A per phase at 2.8V and a holding torque of 3.7kg/cm. (See last month's issue for more on torque.) Note that maximum current flow occurs when the stepper is in the 'hold' position.

There is a range of stepper motor electrical configurations resulting in 4-wire, 6-wire and 8-wire motors. These can be driven in different ways – eg, series and parallel, unipolar and bipolar, normal stepping and micro stepping. (For a detailed coverage of different stepper motor driving techniques, refer to *Using Stepper Motors Parts 1-5*, *PE*, October 2019 – February 2020.)

If you are using a stepper motor in a critical positioning or speed application, I suggest that you buy a suitable stepper motor for your application and also buy the supplier's recommended controller. There's a lot of difference between just making a stepper motor rotate – and having it rotate a repeatable number of steps with high torque. Of course, many commercially available projects that use stepper motors (eg, 3-axis router and mill kits) take this approach, with the motors, controller software and interface all provided.

On the other hand, if all you want to do is rotate a stepper, and you won't destroy precious materials if it gets it slightly wrong (or you're happy to tweak the control system to get the results you want) then microcontroller stepper motor control boards, and standalone low-cost stepper motor controllers, are widely available. For example, the Banggood / AliExpress 'DC8V-27V Programmable Stepper Motor Driver Controller Board Step / Angle / Direction / Speed / Time Adjustable 42/57 Phase' board costs from £10 – £20 and works with most stepper motors connected in a four-wire configuration – See Fig.7. (Do shop around – there is a quite a range of pricing / delivery times). We covered this board extensively in the December 2021 *Electronic Building Block* column.

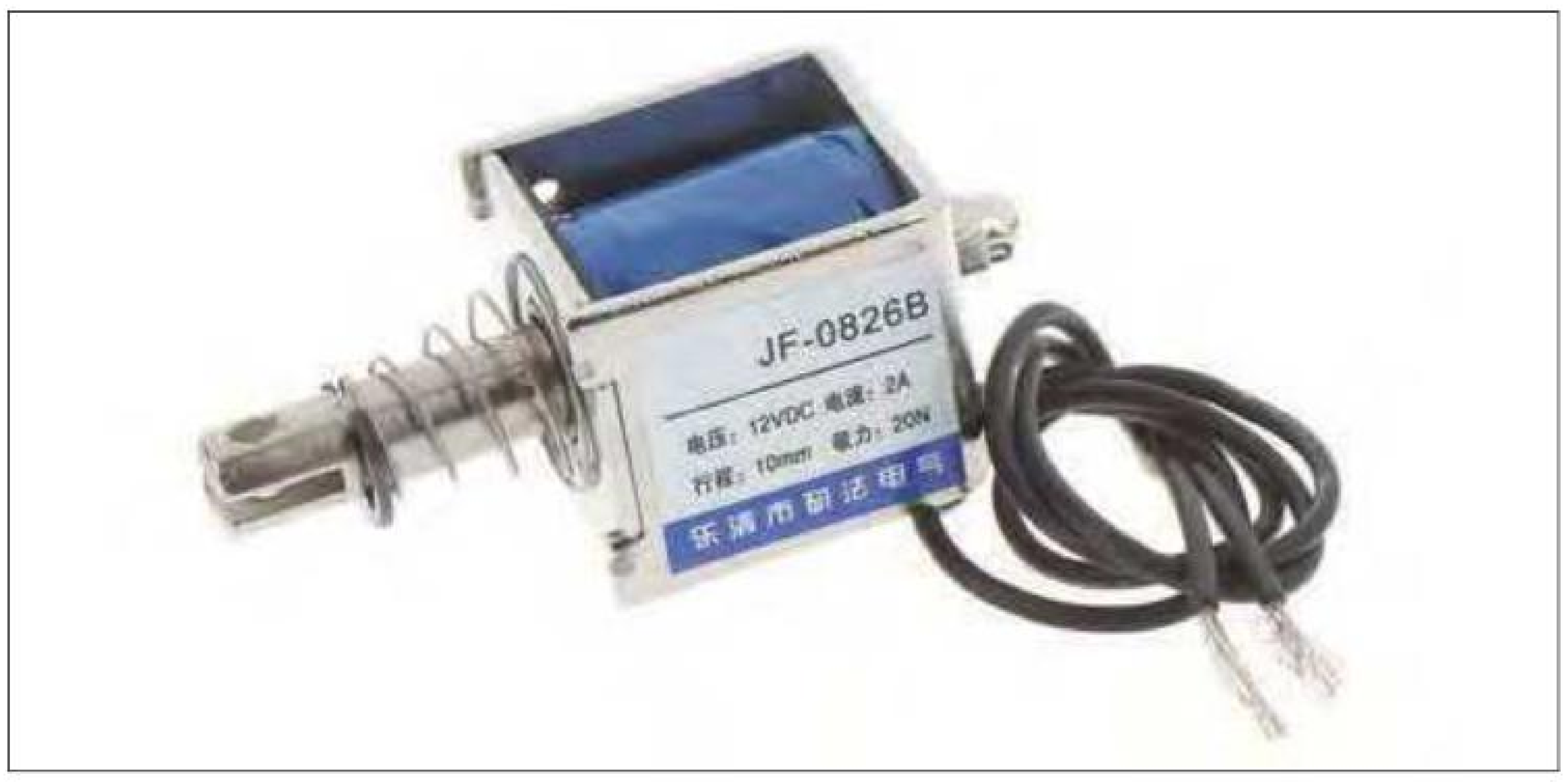


Fig.8. A typical general-purpose solenoid with a spring return. This one is for use on 12V, with a continuous current draw of 2A and a maximum pull of 20N (about 2 kg force.) Cost is low – only about £4.

Stepper motors are excellent where a well-matched electronic control system is being used and precise positioning is required. But they're also useful where high durability is needed – if I had to construct a 24/7 shop window display with a waving hand, then I'd use a stepper motor.

Solenoids

Where an actuator with a short, low force and linear movement is needed, a solenoid is the cheapest and easiest option.

A solenoid consists of a coil wound around a hollow former. Positioned partly inside the former is an iron plunger. When power is fed through the coil, the plunger is pulled fully into the former. As this movement occurs, a coil spring is compressed. When power is switched off to the coil, the spring returns the plunger to its previous position.

Solenoids move very quickly, so they can place high instantaneous loads on whatever they are moving. They also tend to be noisy when triggered, though of course when they're in fully open or closed positions, they don't make any noise at all. Solenoids are specified for:

- Operating voltage
- Continuous current draw (but note that peak current draw on switch-on will be much higher)
- Maximum pull value (usually in newtons).

Most solenoids are rated for continuous duty – that is, they can be held in their pulled-in position with a constant supply of power. Note that solenoids work equally happily on AC or DC.

Ensure that any solenoid you source has a plunger design to which it's easy to make a mechanical connection. Many solenoids have a forked end to the plunger, allowing connection of links via a simple pin, or screw and Nyloc nut. Solenoids are widely available at low prices and old tape recorders – both audio and video – usually have a selection of solenoids that can be salvaged.

If you're using a transistor or similar to drive a solenoid, remember that you will need to fit a freewheeling diode – solenoids create a big inductive spike on switch-off.

Solenoids are ideal for applications like door and cabinet locks, but they can also be used to raise visual indicators (your mail has just been delivered!) or to automate mechanical handles and pull-knobs.

Conclusion

If you wish to develop a mechanical system that is electronically controlled, your options have never been better. There are now plenty of low-cost electronic controllers available, and there's a vibrant retail sector selling mechanical parts. However, the success or otherwise of your project will rest heavily on the actuator(s) you choose and how you drive them.

For high speed and low torque applications, a simple brushed DC motor directly driving the load (eg, a fan) works well. If the torque requirement is high (eg, driving a winch or hill-climbing wheeled robot) then a gearmotor is cheap and effective. For really high torque loads, look towards something like a car windscreen wiper motor. If the required motion is in a straight line, a linear actuator will give reasonably durable and very powerful results. Using inbuilt limit switches or feedback-based electronic controlled, the linear actuator's maximum and minimum extensions can also be easily set. Each of these DC motor-based actuators can also be speed controlled via PWM, and with the use of a more sophisticated controller, the actuator's maximum speed and acceleration can be finely regulated.

If rotational accuracy is needed, torque and power loads are not too high, and the rotation needs occur within an angle of less than 180°, an RC servo can provide all of that – accurately and at low price. RC servos are a good example of a relatively complex product where the price has been driven down by economies of scale – they are brilliant value for money. They can be driven from a microcontroller or, where you want easy control over speed and acceleration, by a more sophisticated controller. However, remember that they're typically not designed for many hours of use – I doubt that one would cope with opening and closing household curtains several hundred times a year, for example.

Stepper motors are good where positional accuracy is paramount – CNC machines, 3D printers and the like. But again, don't miss something that does seem to be a little overlooked – if you want a stepper motor control system to work at commercial levels of accuracy, the motor and controller will need to be well matched. On the other hand, if you just want a very durable motor that needs to operate thousands of hours a year, a stepper motor can provide that too.

Which brings us back to gearmotors. I must admit that the explosion in the number and type of these motors took me by surprise – there are literally hundreds of designs available with different gearing, electrical characteristics and output shaft configurations. Geared right down, and run at low voltage and with position feedback, gearmotors can rival stepper motors for many tasks – and be much simpler to operate. At the other end of the spectrum, they can rotate fast enough to be suitable for high-speed requirements.

And solenoids? To operate, all they need is to have AC or DC power connected or disconnected – and it doesn't get much simpler than that! Truly there's an actuator for every project…

Levers – and car air brakes

When using linear actuators (see last month's issue) and solenoids, levers are especially important. Levers trade higher speed and stroke for greater required actuator force, or vice versa – less required actuator force for slower speed and reduced stroke. (If this sounds familiar, it's just the same as gearing. Gearing comprises continuously rotating levers.)

So, and just for a moment putting on my other hat as an automotive modification writer, let's say we want to create a racing car aerodynamic airbrake, one that rises very fast when the driver puts their foot on the brake pedal. (An air brake creates a lot of aerodynamic drag and thus slows the car very rapidly at high speeds – and all without any concern around tyre skidding on the road or track.)

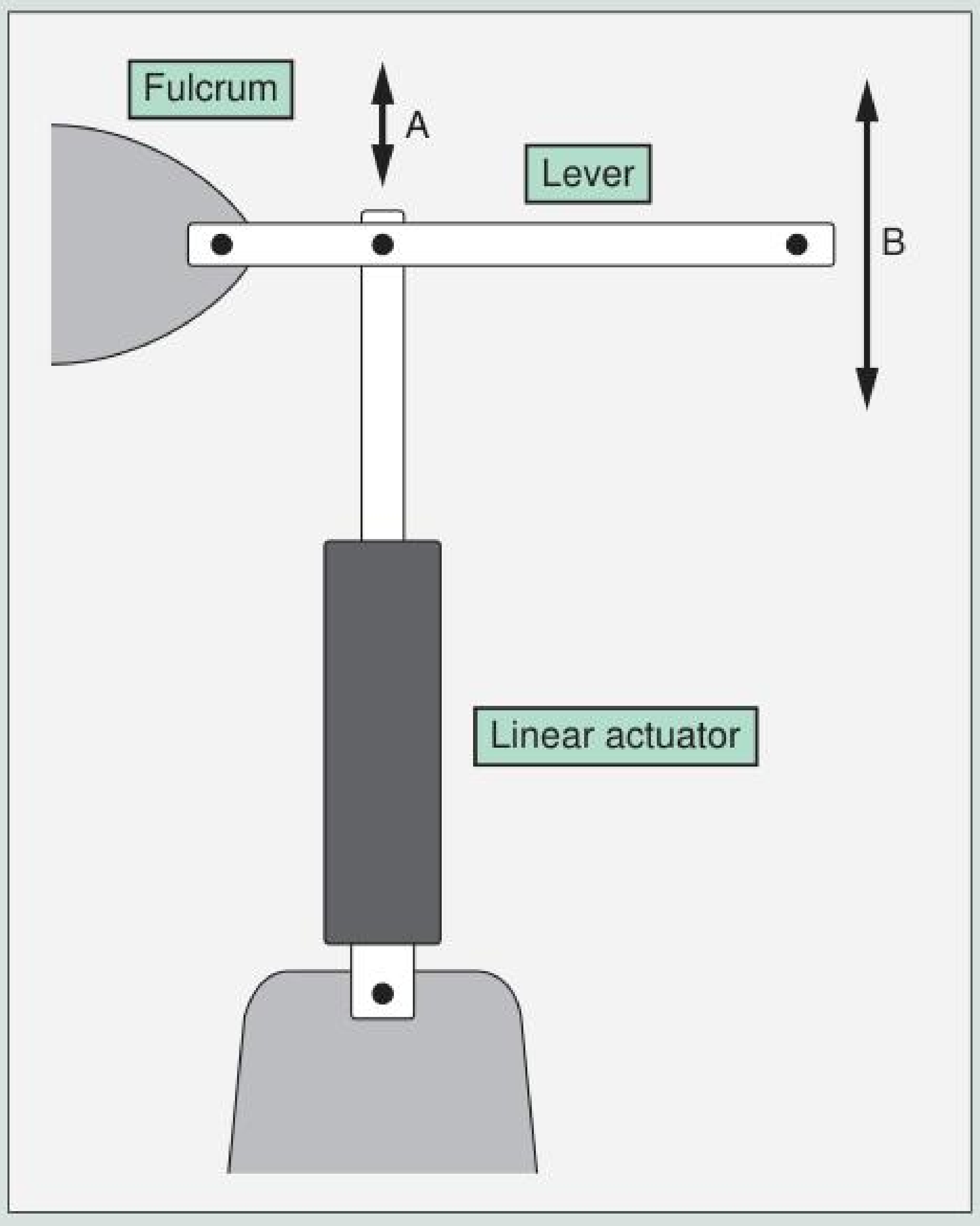


Fig.9. By using a lever, we can increase the stroke and speed over which a linear actuator works – distance B will be larger than distance A, with both achieved in the same time. But you can't get something for nothing – the force that the linear actuator needs to develop increases in direct proportion.

From what we've learned here, an airbrake's up/down movement would be best accomplished by a linear actuator – high force and when power is removed, it locks itself into position. However, these actuators are quite slow – and we'd want an air brake to rise as fast as possible. So what about using a lever to increase the speed of movement? If we put the actuator and the lever's fulcrum (pivot point) close together, with the load at the other end of the lever, we will turn a slow actuator movement into a faster one (Fig.8). But, at just the same rate as the increase in speed, we will also increase the force the actuator has to exert.

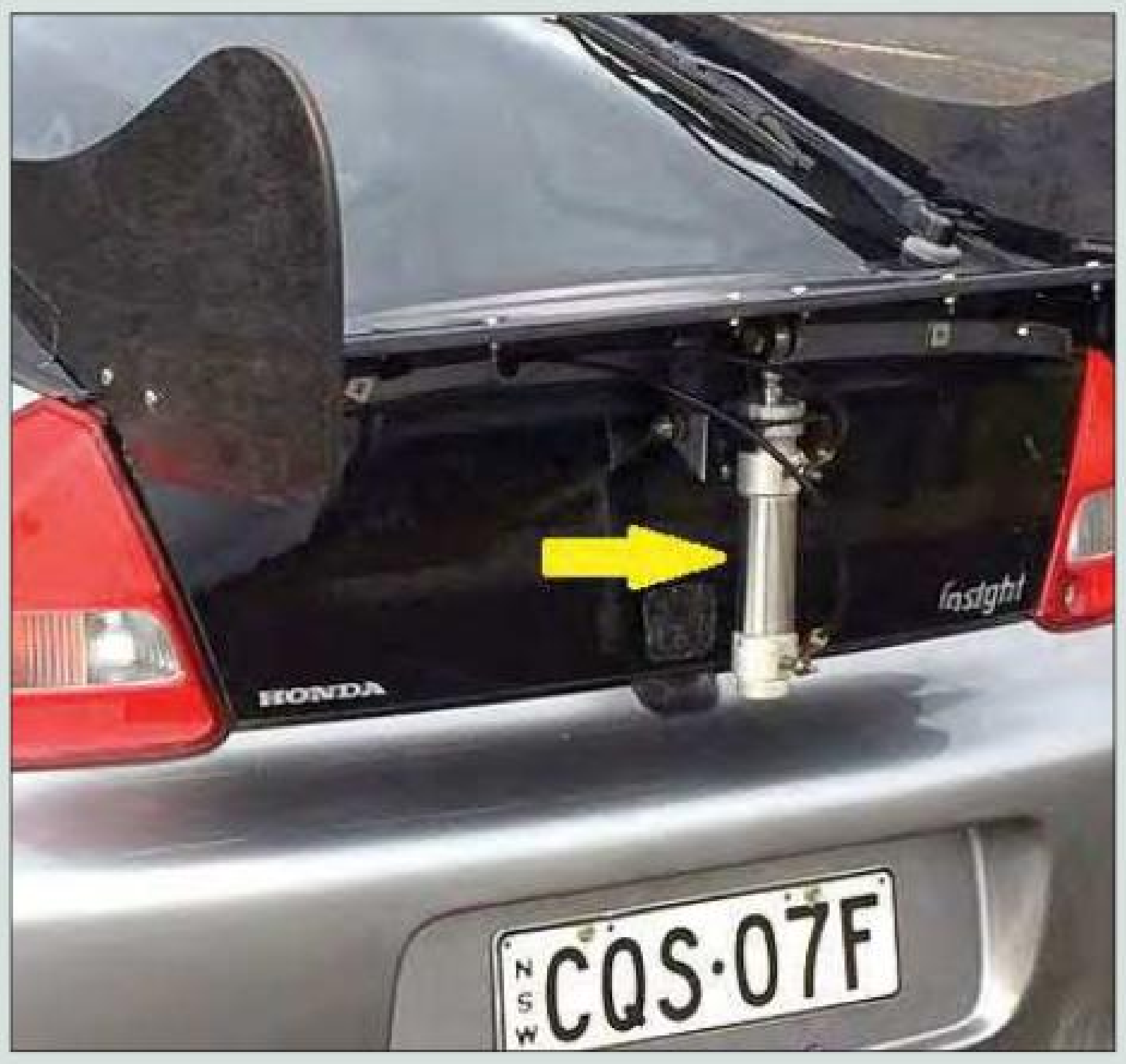


Fig.10. A trial rear aerodynamic air brake on a road car. When braking, the panel between the side fins was rapidly raised through about 80 degrees. The speed of the required erection, and the forces involved, meant that no off-the-shelf electrical actuator could do it – no matter the leverage applied. But a pneumatic cylinder (arrowed) could. And the result? At very high speed the brake was excellent – but unfortunately, at legal speeds, it was rather weak. Oh, if only to drive every day in Germany…

So let's say a linear actuator extends fully over 5 seconds, and we want to arrange a lever to make the airbrake extend fully in just 0.2 seconds. That's a 25:1 ratio – so the force on the linear actuator goes up by just the same ratio. Hmm…, it depends on speed and air brake area, but let's say that at full deployment, the airbrake has a force acting on it of 300N (that is, the force that is trying to close it). 300N multiplied by 25 = 7500N! In reality, the required force won't be quite as high as this (because at any angle less than full deployment, the air brake will exert less force) but the back-of-the-envelope calculations quickly show that no normal linear actuator is going to meet the requirement. (In fact, in this situation, I used a pneumatic cylinder backed by a lot of air pressure. It didn't quite meet the force requirement, but it came close.)

So, while levers are very effective in mechanical situations of the sort we are describing, remember that you can never get something for nothing – there will always be a trade-off in terms of speed/stroke or required actuator force.

Max's Cool Beans

By Max the Magnificent

Flashing LEDs and other engineering temptations – Part 33

One of the things that never ceases to amaze me is how little I know and how much I have yet to learn. In an earlier column (*PE*, September 2022) I waxed eloquently about the topic of servo motors and their gears and gear trains. As part of this, we noted that, although some people – especially in the UK – informally refer to gears (a.k.a. gearwheels) as 'cogs,' the term 'cog' officially denotes an individual tooth on a gear.

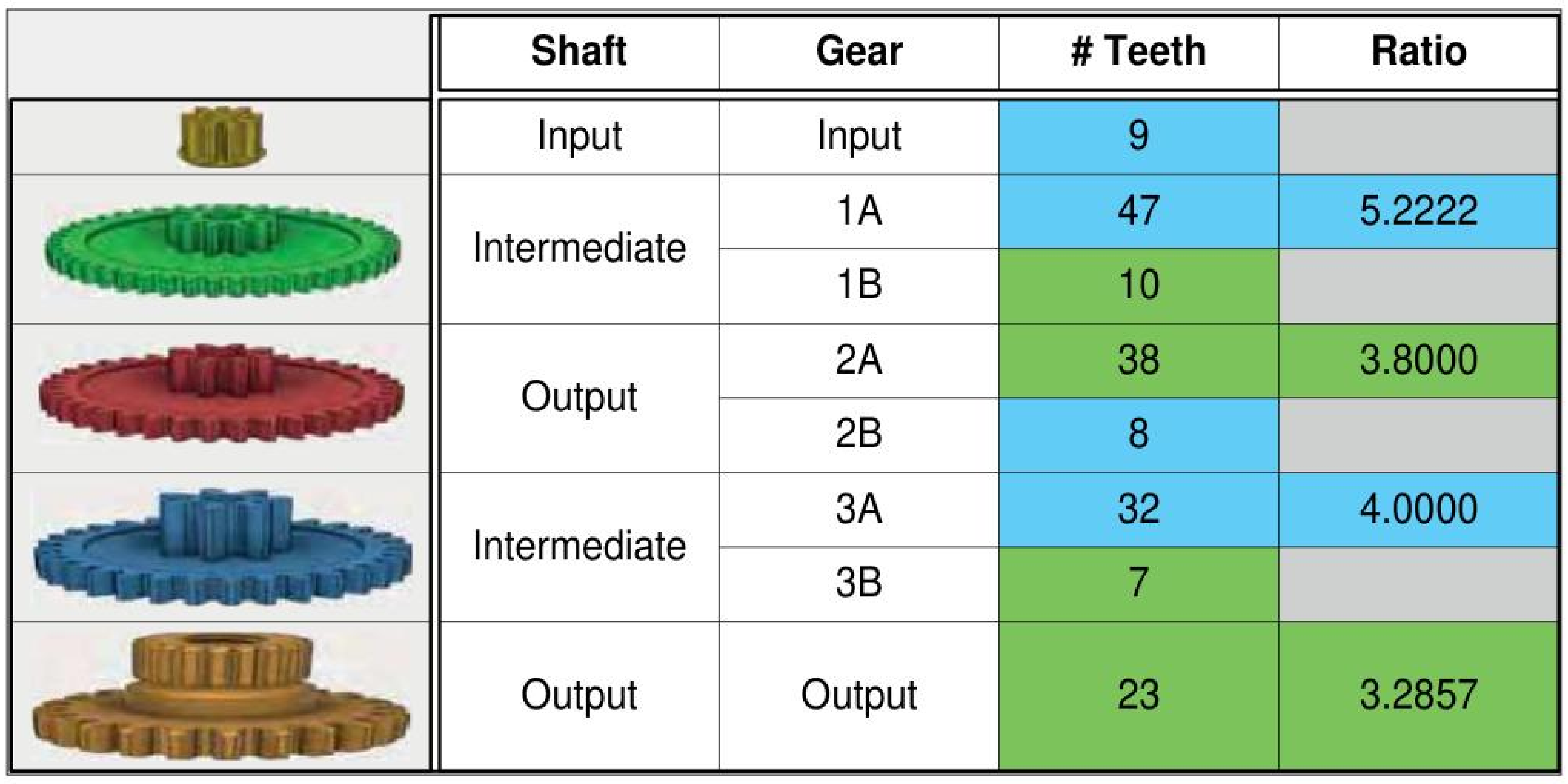
The wheels are turning

Following that column, I received an email from retired mathematician, physicist and engineer Peter Brearey, who said: 'One point you did not mention (and evident in the example gear train you showed) is that the ratio should have no common factors such that each cog on one gear wheel will interact with every cog on the coupled gear wheel to ensure even wear and to allow the gear train to be dis-assembled and rebuilt without problems of binding and ill-fitting.'

As soon as I read this I thought, 'that makes perfect sense.' It also struck me that this probably wasn't something I would have thought of for myself. A lot of this sort of thing was conceived in the distant past when mechanical engineering and steam-powered machines dominated the technological landscape. It makes me realise that our engineering predecessors knew a lot of stuff about a lot of stuff.

Thinking about this caused me to revisit the gears forming the gear train in the simple servo my friend Steve Manley dismantled and modelled (Fig.1). The 8:32 ratio between stages 2B and 3A immediately caught my eye, so I emailed Peter back asking: 'Re your point about gear wheels not having common denominators with respect to the number of their cogs. In the servo we broke down in the September issue, we do have an 8 to 32 cog transition between 2B and 3A (Steve just recounted the cogs to make 100% sure), so is this the exception that proves the rule?'

Peter responded saying that this was indeed an unfortunate ratio, adding: 'The 10:38 ratio between 1B and 2A also is not so good. It would have been better to use 11:38 for 1B and 2A then 8:33 for 2B and 3A. But in this instance, it is unlikely users would dis-assemble the gear train then re-assemble it later; also, the wheels are plastic, so they would easily re-profile themselves provided they were made to a reasonably close tolerance. It is just that the more precision you want, the greater the need for gear ratios to have no common factor. A tolerance of 1/100 is less onerous than 1/1,000 or 1/10,000. It is horses for courses, and where wear and/or breakage can be best tolerated. And for mass production, cost and reusability of parts and ease of assembly without errors is important (notice the colouring of the wheels). Mass production compared with a one-off hand-tuned item is like comparing chalk to cheese.'



	Shaft	Gear	# Teeth	Ratio
	Input	Input	9	
	Intermediate	1A	47	5.2222
		1B	10	
	Output	2A	38	3.8000
		2B	8	
	Intermediate	3A	32	4.0000
		3B	7	
	Output	Output	23	3.2857

Fig.1. Summary of servo gear train.

Analogue magic

I've noticed that my meandering musings seem to be stirring up a lot of reader memories. In my previous column (*PE*, October 2022), for example, I touched on the topics of using mercury delay lines and magnetic core stores for early digital computer memory subsystems.

This prompted a retired physicist and software engineer (just call me 'Jim') to email me saying: 'Hi Max, I just read your latest *Cool Beans* article and enjoyed it as always. I have an interesting anecdote to share with you. Way back in the 1980s I was doing my PhD at Warwick University using a clapped-out Auger electron spectrometer that I mostly had to rebuild, often from scratch, and that used exclusively analogue electronics. It was connected to an equally clapped out GEC4080 mainframe that used core memory, a primitive analogue-to-digital converter for signal measurement, and an equally primitive digital-to-analogue converter for control of the spectrometer. One day, halfway through a lengthy experiment, we had a complete power cut for about 15 mins. Of course, all the equipment and computers, including the GEC went down. When the power came back up, the BBC Micro in our lab promptly proceeded to format both its floppy disks, and all of the (then) fancy digital equipment either rebooted or hung in some obscure state. My equipment powered up perfectly and took its next data point as though nothing had happened. So, analogue electronics + core memory = magic. Actually, this incident opened my eyes, because this is how all electronics should work, and will work in the future as soon as we get truly persistent memory.'

Jim went on to say: 'One of my lecturers at Warwick told me the following story about mercury delay lines. He was working on one of the first computers and they had a long delay line that was a glass tube filled with mercury that stretched right across the lab. They built a comfy bench over it to protect it and so they could sit down. Immediately they noticed random bugs. Those old computers depended entirely on the time of flight of pulses down the

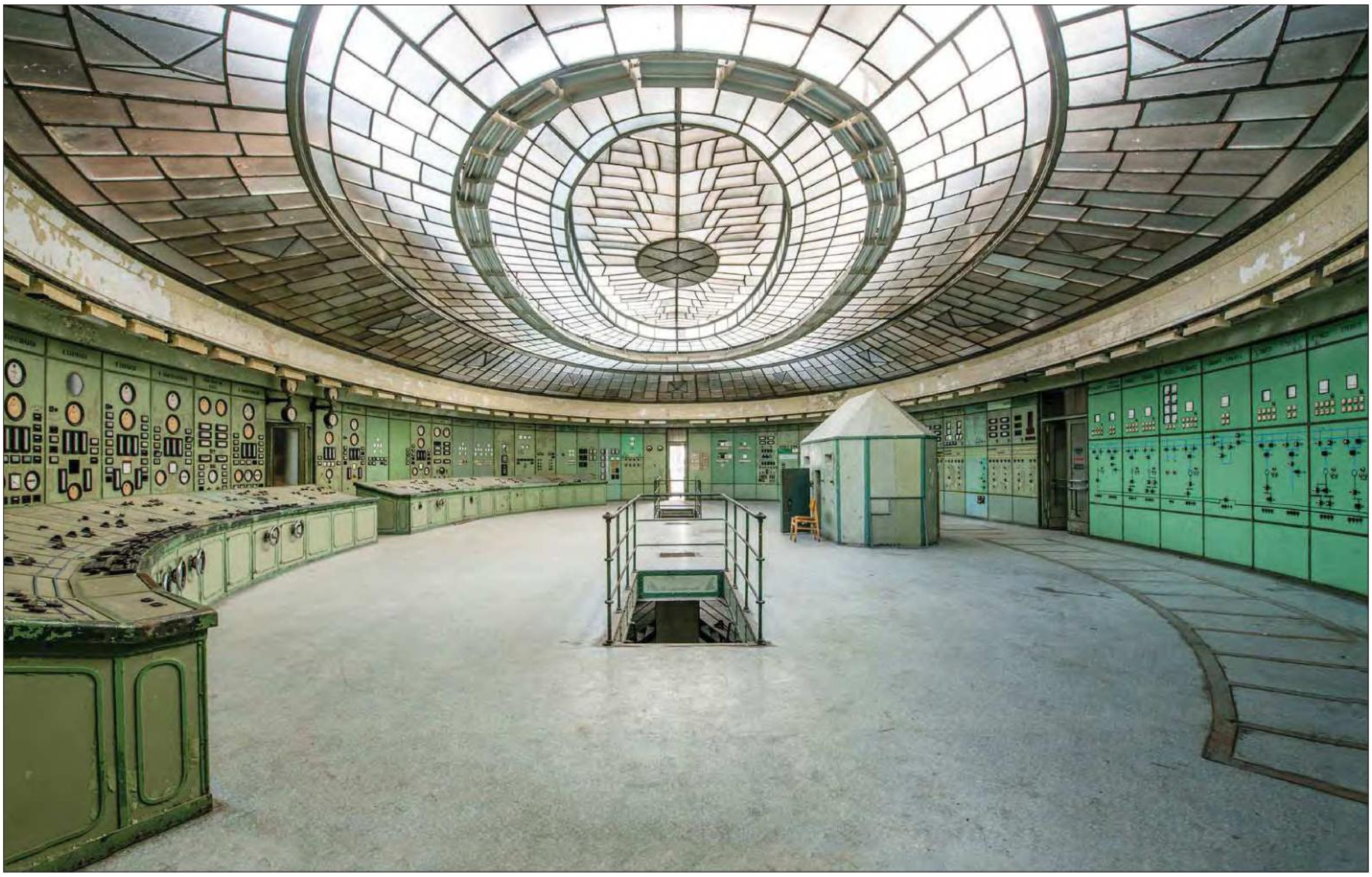


Fig.2. Abandoned power plant in Hungary. (Image source: André Joosse)

delay line, and they eventually figured out that whenever someone sat on the bench, their backside warmed the mercury up just enough to slow the pulses and introduce a bug.'

He closed by saying: 'Sometimes I long for the days when a power switch was a switch rather than a negotiation.' I have to say this latter point brought a wry smile to my face because I'm currently doing some work with switches myself and I know just what Jim means.

I'm as happy as a clam

In earlier columns I made mention of the fact that I was heading out to Trondheim in Norway at the beginning of September. While there, I gave a guest lecture to the Embedded Computing students at the Norwegian University of Science and Technology (NTNU). I also gave the keynote presentation at the FPGA Forum, which is the place to 'see and be seen' if you have anything to do with FPGAs in Norway and nearby countries. I'm happy to report that both of my talks went down rather well (well, no one threw anything at me, which I always take to be a positive sign). If you are interested, you can learn more about these talks by bouncing over to **https://bit.ly/3BlWJTr** and **https://bit.ly/3xvOZx3**, respectively.

One of the things I shared with the students is the concept of 'urbex' (urban exploration), which refers to the exploration of manmade structures, usually abandoned ruins or hidden components of the manmade environment. Although targets of exploration vary from one country to another, high-profile abandonments include amusement parks, grain elevators, factories, power plants, missile silos, fallout shelters, hospitals, asylums, prisons, schools, poor houses and sanatoriums.

I don't know why, but I love wandering round old buildings like factories and power plants. I also love seeing pictures of these things. Maybe it's my interest in post-apocalyptic science fiction stories. The main thing is that I'm not alone, because a lot of other people are also interested in this sort of thing.

One of my heroes in this area is André Joosse, who hails from the city and municipality of Goes in the southwestern Netherlands on Zuid-Beveland, which is in the province of Zeeland. André's website boasts myriad awesome urbex photos (**www.urbex.nl**). One of my favourites, which André kindly gave me permission to share with the students and with the readers of *PE*, is of an abandoned power plant in Hungary (Fig.2.).

In the case of the students, I used this as the lead-in to talk about old display technologies. For the purpose of our discussions here, however, I just want us to feast our orbs on this bodacious beauty. To be honest, words fail me. A lot of what we build these days is a 'tribute to concrete' and lacks even the rudiments of style. By comparison, the control room in André's photograph positively projects panache.

I'm as sick as a parrot

Speaking of parrots (we weren't, but we are now), in my previous column we experimented using two 2-axis joysticks to control two pan-and-tilt servo mechanisms. Since we were feeding the signals from the joysticks directly into an Arduino Uno, this required four of the Uno's analogue input pins. Similarly, since we were driving the servos directly from the Uno, this required four of its pulse-width modulated (PWM)-capable digital output pins.

In the case of the animatronic head created by Steve Manley with (occasionally useful) suggestions by your humble narrator (*PE*, March, April, and May 2022), we have two 3-axis joysticks and seven servo motors. Your own projects (and our future projects) might boast many more control inputs and servo outputs.

As result, in this column I was originally planning on talking about using I^{2}C-based analogue breakout boards (BOBs) to gather the signals from multiple analogue inputs, along with I^{2}C-based servo controller BOBs, each of which can control 16 servo motors. The result would allow us to monitor large numbers of analogue inputs and control large numbers of servo motor outputs using just two pins on our microcontroller.

The reason I'm not, in fact, talking about this is that I'm currently feeling

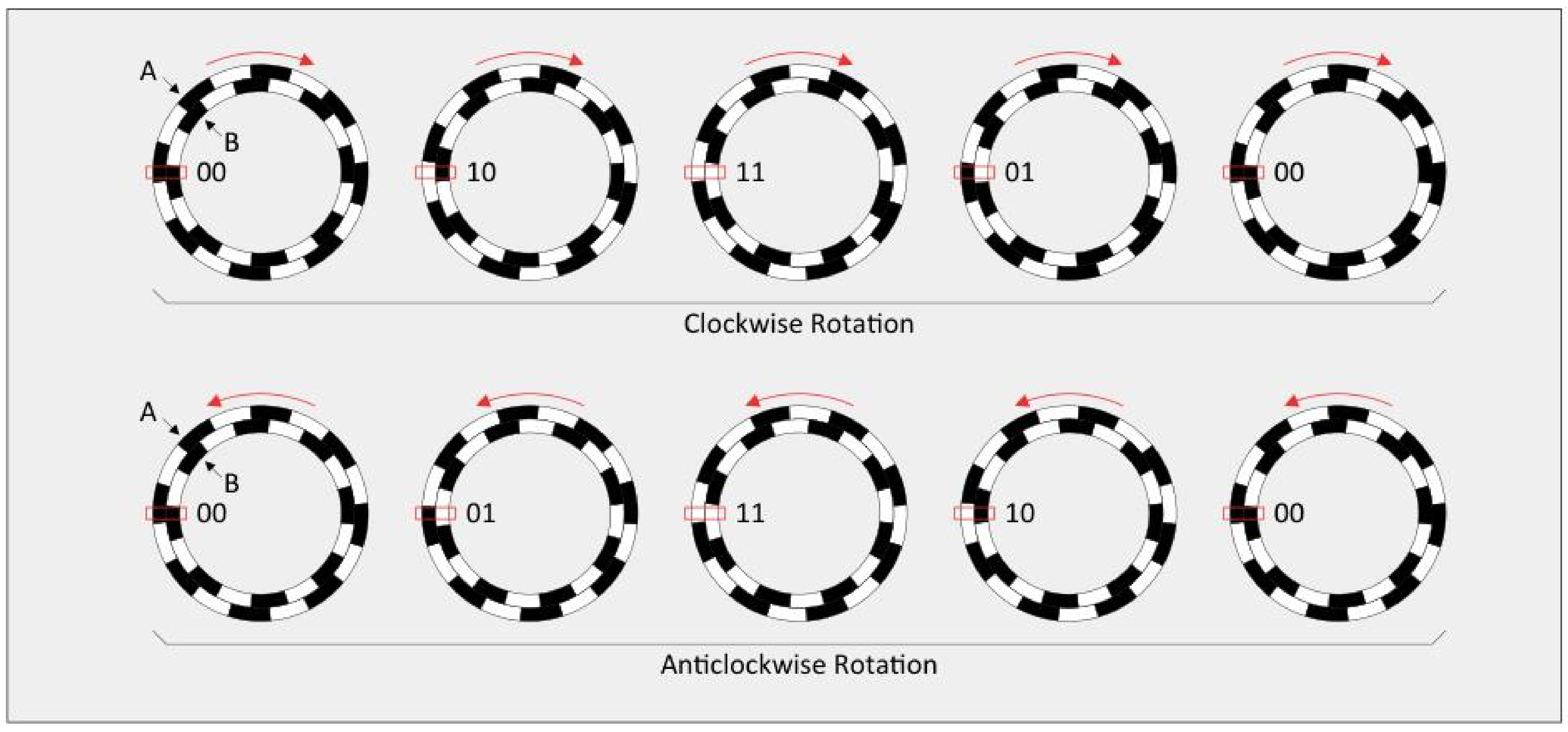


Fig.3. Conceptual working of rotary incremental quadrature encoder.

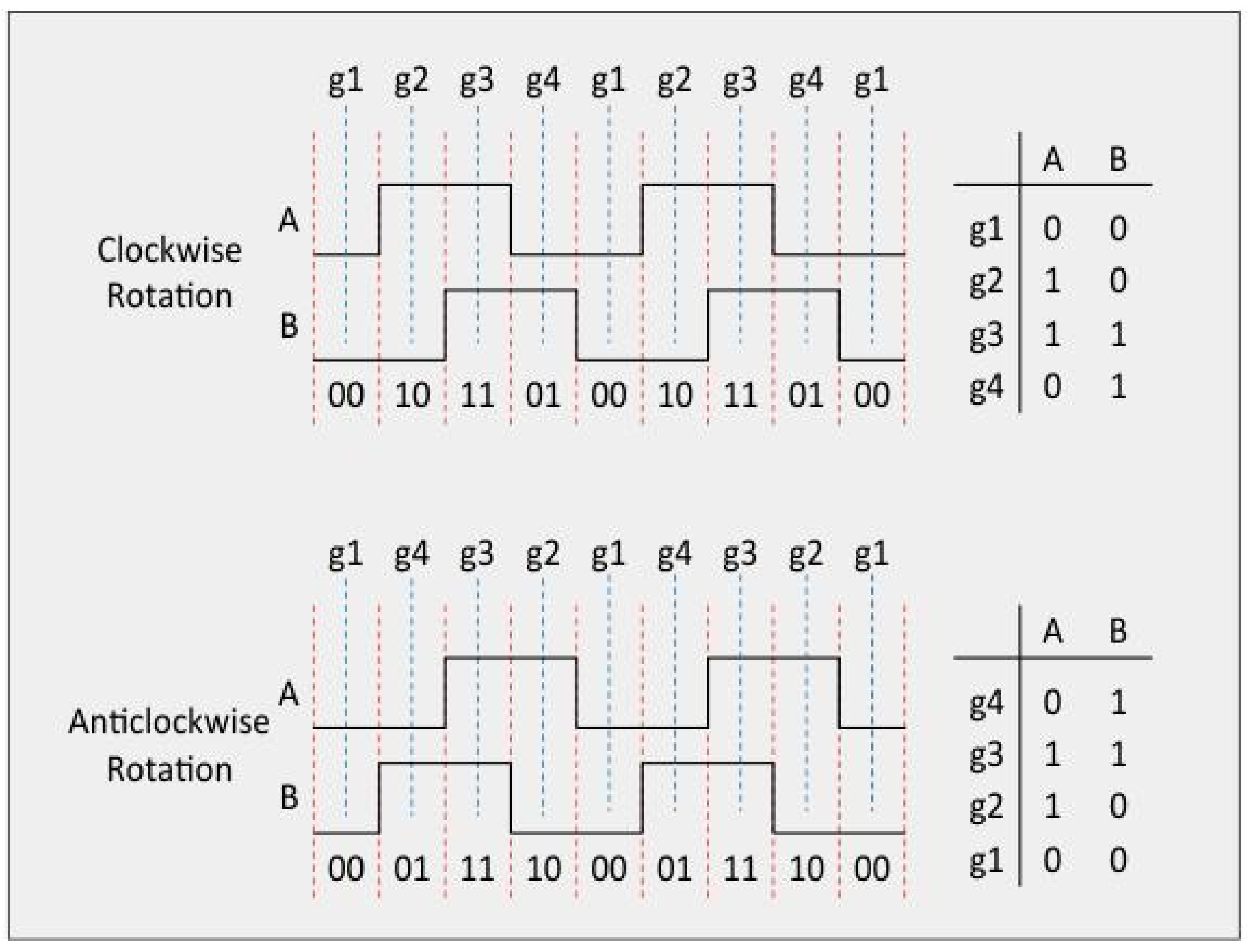


Fig.4. The leading signal is used to determine the direction of rotation.

as sick as a parrot. I'm not sure as to the origin of this phrase. Some sources say that it derives from the fact that some parrots will feed on fermenting (alcoholic) fruit and end up suffering from a hangover. I also read that Aphra Behn, who was an English playwright, poet, prose writer and translator from the Restoration era, started the ball rolling in her 1682 comedy, *The False Count*, in which the maid Jacinta says of her mistress Julia, 'Lord, Madam, you are as melancholy as a sick Parrot.'

Whatever the source of this expression, I'm certainly not wearing my happy face. When Steve and I first commenced work on our animatronic noggin project, I visited the workshop of my friend 'Carpenter Bob' and constructed a couple of small wooden testbenches to hold my joysticks and servos (*PE*, March 2022). Meanwhile, Steve set to work creating his 3D-printed masterpiece.

When Steve's far superior realisation was finished, he kindly built one for me, which resulted in my proudly 'holding my head in my hands' (*PE*, May 2022). A few days before setting off to Norway, since I had occasion to go downtown, I decided to take my fully-fledged animatronic head to Bob's workshop to show him how our original prototype had evolved.

It has to be said that Bob was duly impressed, proudly presenting it to anyone who visited his workshop while I was there. However, when I returned to my office, I foolishly left my head in the trunk (boot) of my car (and that's not something you expect to hear yourself saying on a regular basis). I really didn't think anything about the weather, but it turned out that the outside temperature tickled 100°F (~38°C) later that afternoon.

The reason for my frowny visage is that, when I returned home and went to retrieve my head, I discovered that it was a sadly drooping incarnation of its earlier self, strangely reminiscent of Salvador Dalí's melting clocks in *The Persistence of Memory* – see: **https://bit.ly/3BOHJPu**

I'd show you a picture of my animatronic noddle, but I don't want to make you cry. Fortunately, as you may recall, Steve very kindly made his 3D design files available for use by anyone who wants to create their own animatronic masterpiece. You can download a compressed ZIP (file **CB-May22-01.zip**) containing these design files from the May 2022 page of the *PE* website (**https://bit.ly/3oouhb**l). So, that's just what I'm going to do, thereby restoring my precious pate to its former glory (watch this space for more details).

Ravishing rotary encoders

A few months ago, I read the biography of Leonardo da Vinci by Walter Isaacson (**https://amzn.to/3xvzbu6**). One of the things I learnt was how Leonardo had the ability to notice 'stuff.' For example, I've looked at a lot of trees in my time without thinking anything more profound than 'That's a pretty tree.' By comparison, Leonardo whipped out his tape measure and determined that the sum of the cross-sectional areas of tree branches above a branching point is equal to the cross-sectional area of the trunk (or the branch) immediately below that branching point. Genius!

I feel like an old fool (but where are we going to find one at this time of the day?). The reason I say this is that I've come to the realisation that I largely meander my way through life without really noticing anything that's going on around me. My wife (Gina the Gorgeous) has said this about me for years. Earlier today, for example, she proclaimed, 'You haven't been listening to a word I've said!' And I thought, 'Well, that's a strange way to start a conversation.'

Recently, someone asked me a question about switch bounce in the context of digital rotary encoders. At first, I thought we were talking about rotary switches, but it turned out that the topic in hand was something completely different.

Consider the volume control on a car radio, for example. In the not-so-distant past, this would have been implemented using a potentiometer (variable resistor) with a fixed range of rotation. More recently, this control will be implemented using a rotary encoder that has a tactile 'click-click-click...' feel as you rotate it. One point of interest here is that there are no 'end stops' per se; that is, you can keep on rotating these things clockwise or anticlockwise to your heart's desire.

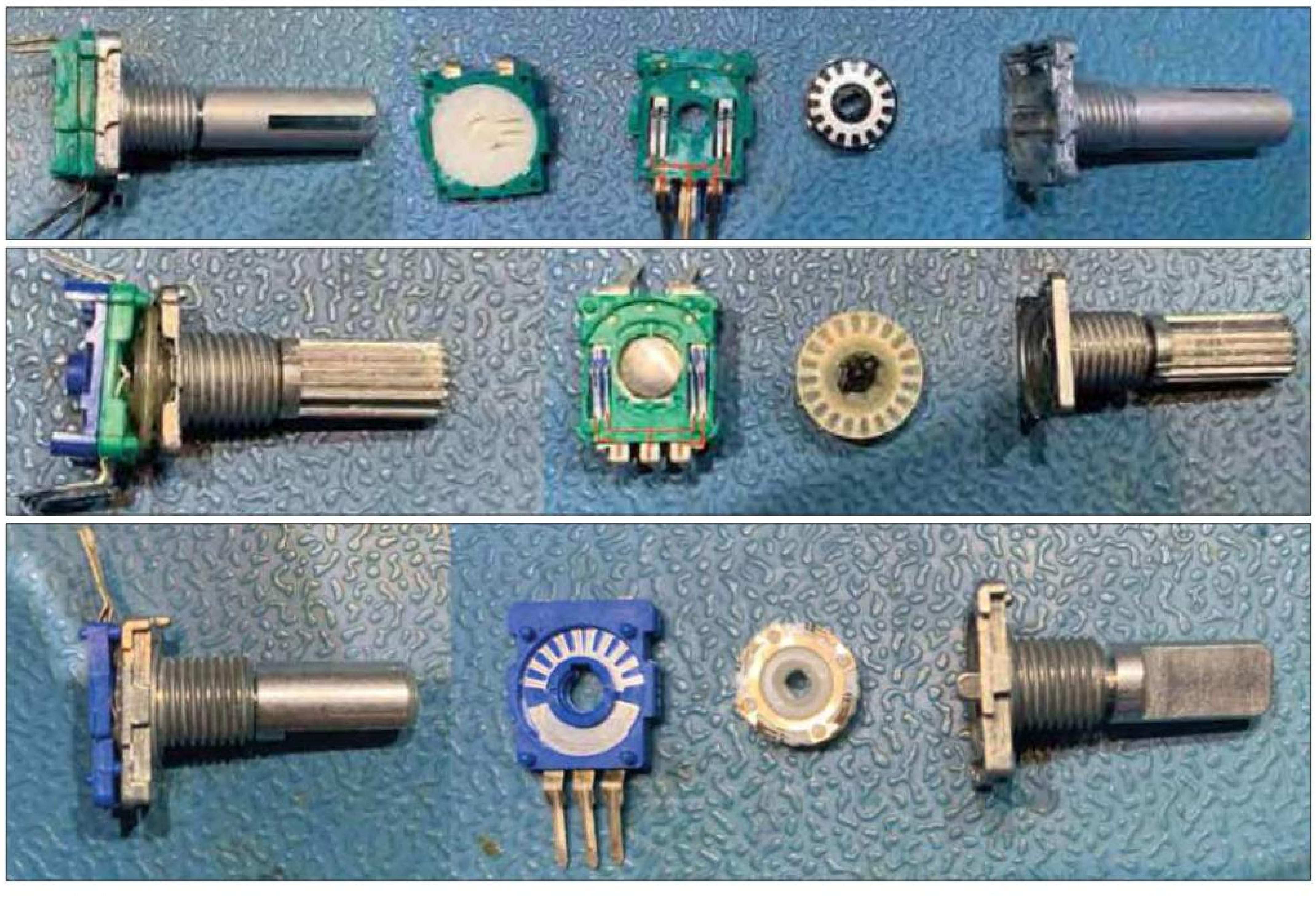


Fig.5. 30-click (top), 20-click (middle), and 20-click (bottom) (Image: Joe Farr).

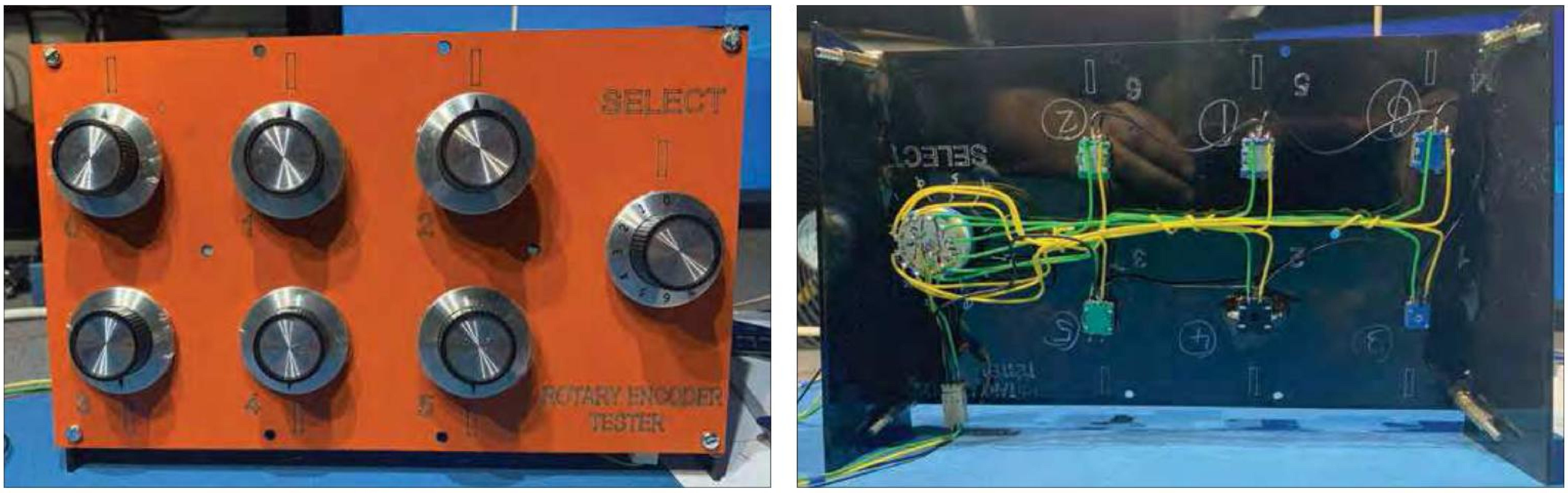


Fig.6. Testbench to evaluate six different rotary encoders. (Image: Joe Farr)

I must admit that I had vaguely noticed these characteristics in my own car, but I never paused to ponder this phenomenon in more depth (I bet Leonardo would have caught onto this immediately). It turns out that these little rascals are being deployed everywhere. In my car, for example, there are two on the radio (volume and tuning) and three on the air conditioning system alone.

After a little investigation, I discovered that there are all sorts of these little scamps. Let's start with the fact that there two main types, which we can class as absolute and incremental. A digital absolute encoder produces a unique digital code for each distinct angle of the shaft. By comparison, an incremental digital encoder will report changes in position, but it will not report or keep track of absolute position.

The encoding for both types can be implemented using mechanical, optical, magnetic or capacitive technologies. For the purposes of these discussions, we are focusing on mechanical incremental quadrature digital encoders because these cheap-and-cheerful devices appear all over the place. Also, there are lots of examples available on Amazon for use with hobby projects, see: **https://amzn.to/3di9mHf**

Easy peasy lemon squeezy

When I first started to investigate this topic, the explanations all seemed to be relatively simple and straightforward. Let's start with the fact that there will be three pins coming out of the encoder. One will be a common signal that we will connect to ground. This will be accompanied by two encoded signals called A and B to which pull-up resistors will be attached. A conceptual drawing of a rotary incremental quadrature encoder sensor mechanism with corresponding logic states of the A and B signals is shown in Fig.3.

In this conceptual implementation, the A and B signals are connected to contacts on two rings. We can think of the black areas as being copper connected to ground (logic 0). Also, we can visualise the white areas as not being connected to anything, which will let the pull-ups on the A and B signals pull them to logic 1. As a result, the A and B signals are 90° out of phase. In turn, this results in four 'Gray code' (**https://bit.ly/pe-nov22-gray**) combinations of A and B that we might label g1, g2, g3, and g4. If A leads B, then the mechanism is rotating clockwise. If B leads A, then the mechanism is rotating anticlockwise (Fig.4).

When you see these diagrams, things do look relatively easy, don't they? It's true that my own knee-jerk reaction was to think that all we had to do was connect the A and B signals to two digital inputs on a microcontroller – let's say an Arduino Uno to keep things simple – and 'Bob's your uncle' as they say (or aunt, depending on one's family dynamic).

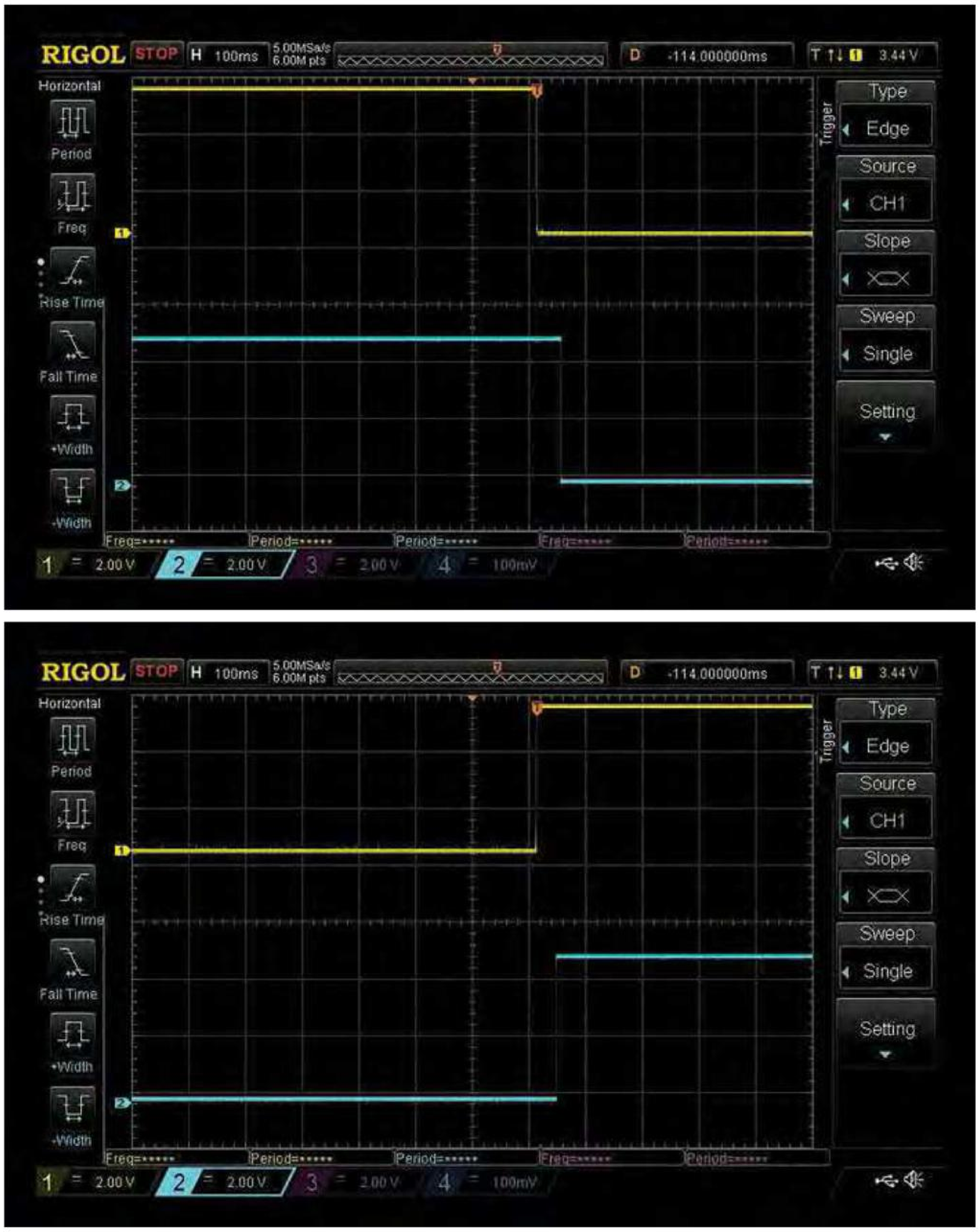


Fig.7. 30-click device: a) (top) turning the knob one click clockwise; and then b) again.

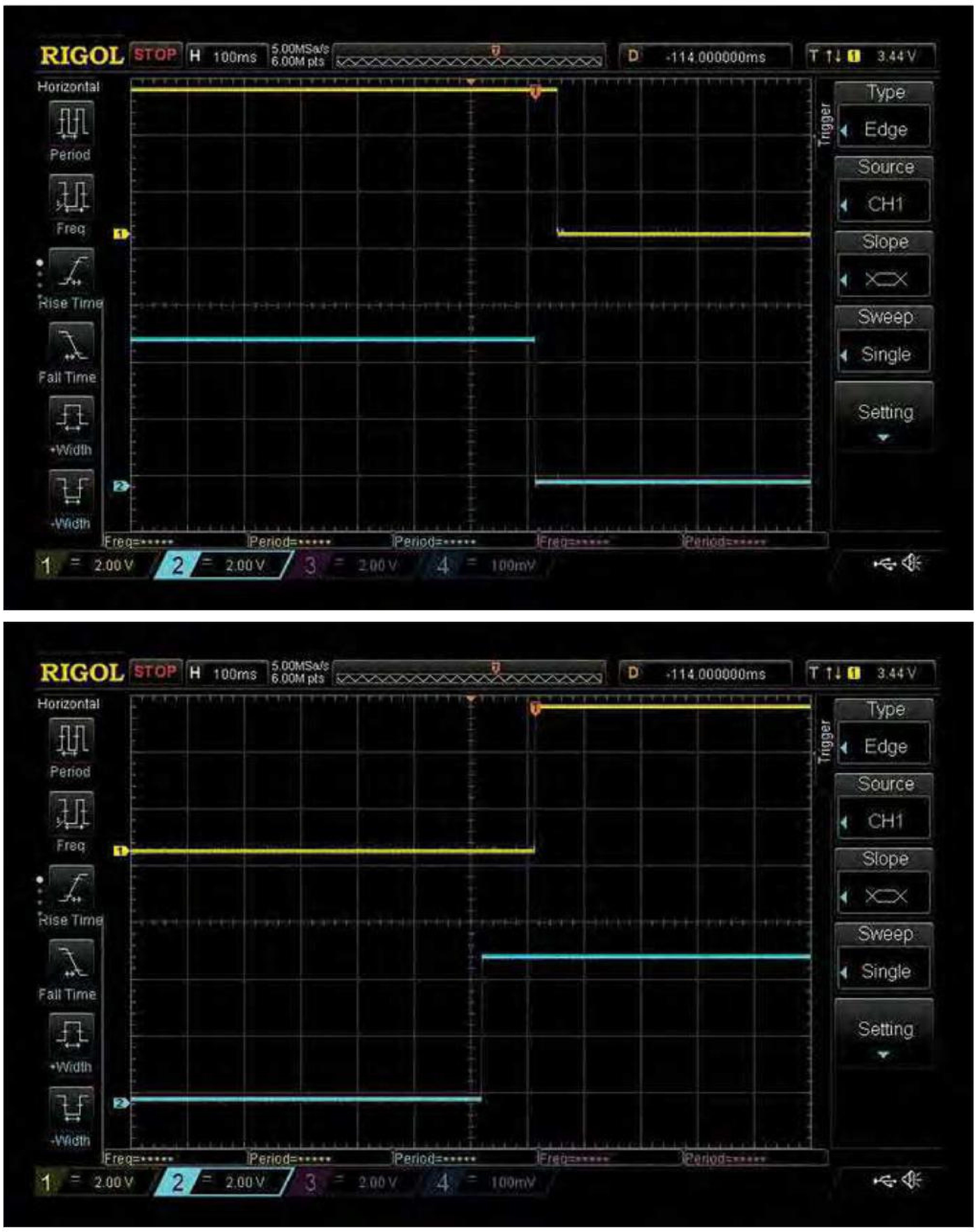


Fig.8. 30-click device: a) (top) turning the knob one click anticlockwise; and then b) again.

Not so simple

Of course, nothing in life is simple. I was chatting to my friend Joe Farr, who hangs his hat in the UK, and he mentioned that he's had some non-intuitive experiences with rotary encoders in the past. As a result of our discussions, we both ordered a bunch of different encoders and dismantled them to see what was inside. Give me strength – each one was implemented in a different way (see Fig.5)!

You may remember my saying that these encoders have a tactile 'click-click-click…' feel as you rotate them. This is implemented by mechanical means using small indentations in the casing. The result is that the switch settles into a specific state following each click.

Let's start with the 30-click device, which has 30 mechanical indentations (Fig.5 top). Joe has highlighted the common signal and the A and B signals in red. The A and B contacts are slightly staggered (offset), thereby resulting in the quadrature encoding. Of particular interest here is the fact that the encoding disk itself has only 15 'spokes,' as it were. What this means is that if the A and B outputs start at 11, then after one 'click' in any direction they will end up at 00. Another click will result in them being 11 again. Remember that it's the signal that changes first that's used to determine the direction of rotation.

Now consider the first 20-click device, which has 20 mechanical indentations (Fig.5 middle). In this case, the encoding disk also has 20 'spokes.' As a result, the A and B outputs always start with a value of 11. Following a click, they will end up back at 11 again, but they will have passed through the intermediate 10, 00, 01 (or 01, 00, 10) values on their way. Once again, it's the signal that changes first that's used to determine the direction of rotation.

Finally, take a look at the second 20-click device, which also has 20 mechanical indentations (Fig.5 bottom). This one really made us scratch our heads for a while. Let's start with the blue plastic piece on the left. In this case, the big area of metallisation is connected to the common pin in the middle and this common pin will be connected to ground. The A and B pins on each side are connected to the two 'spoke' areas at the top, each of which has five 'spokes.' Now consider the rotating disk in the middle. This is what's connected to (driven by) the main shaft. This disc carries four conducting contacts that are connected and mounted at 90° to each other. This means that at least one of these contacts is always in touch with the main ground area, while two of the three remaining contacts interface with the two 'spoke' areas. It's difficult to wrap your brain around how this works (and also why anyone would decide to implement it this way in the first place), but the end result is that it generates similar signals to the first 20-click device.

Our next step was to observe the inner machinations of different devices on an oscilloscope, for which purpose Joe created a small test bench, as illustrated in Fig.6.

Suffice it to say that more surprises were in store. For example, in some of these devices, what are labelled as being the A and B outputs in the data sheet operate the opposite way round to what you would expect in terms of which transitions first. Of course, it's easy to swap the wires going to your microcontroller or to address the issue in software. Nonetheless, it's a tad disconcerting to discover that two devices from different vendors that purport to operate in the same way have their A and B outputs swapped over.

Let's get testing

We'll start with one of our 30-way devices. In this case, we started with both A (top) and B (bottom) being 11; had the knob been rotated one click in either direction, however, they would have commenced at 00. Turning the knob one click clockwise resulted in the waveforms shown in Fig.7a, ending up with A and B at 00 (A transitioned first). Turning the knob one more click clockwise resulted in the waveforms shown in Fig.7b, ending up with A and B back at 11 (again, A transitioned first).

Similarly, turning the knob one click anticlockwise resulted in the waveforms shown in Fig.8a, ending up with A and B at 00 (B transitioned first). Turning the knob one more click anticlockwise resulted in the waveforms shown in Fig.8b, ending up with A and B back at 11 (again, B transitioned first).

Next, let's look at one of the 20-way switches. In this case we always start with the A and B signals in a 11 state. Turning the knob one click clockwise resulted in the waveforms shown in Fig.9a, with A (top) and B (bottom) passing through the 10, 00, and 01 states, ending up with A and B returning to 11 (B transitioned

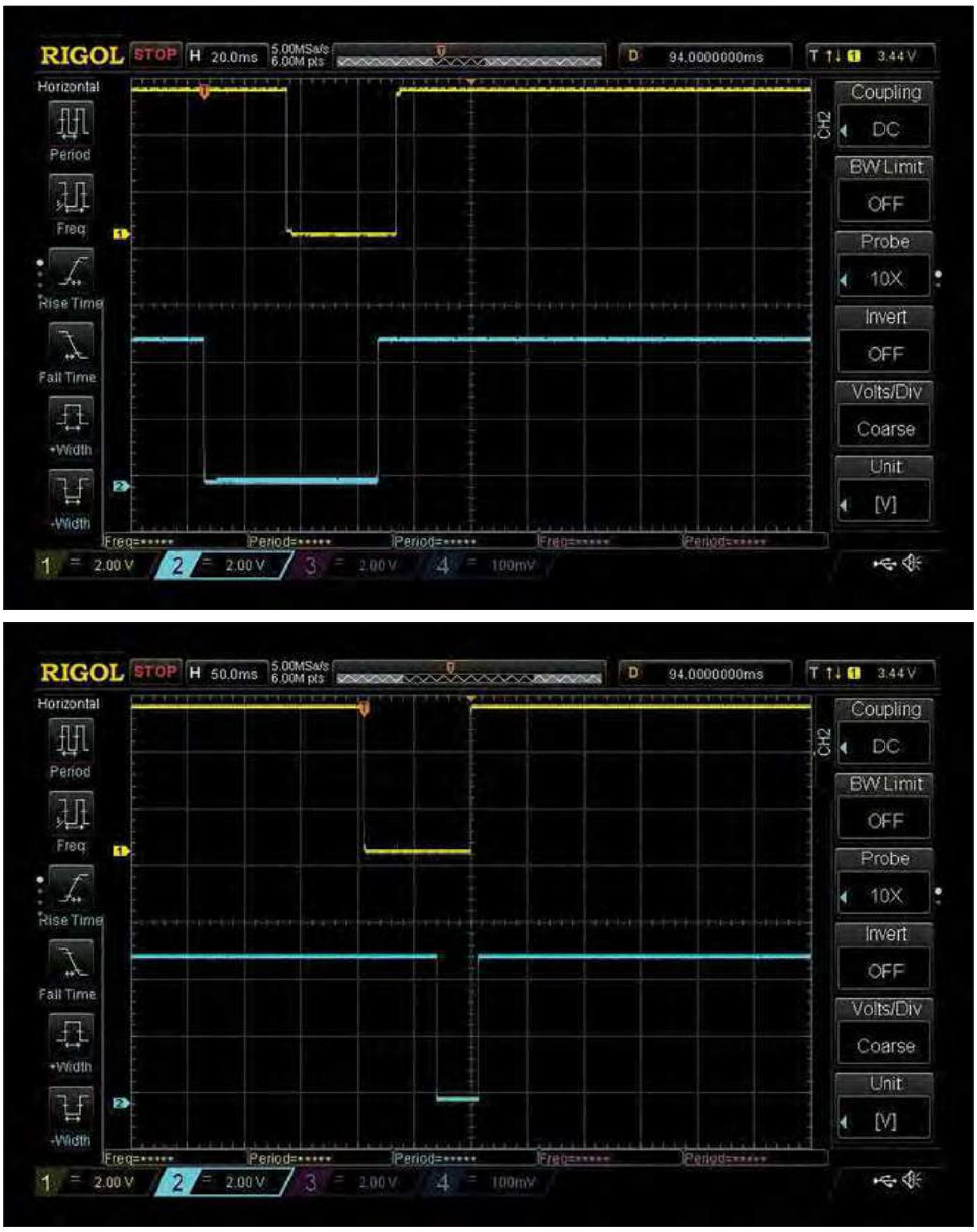

RIGOL
STOP
H 20.0ms
5.00MSa/s
6.00M pts
D 94.0000000ms
T 3.44 V
Horizontal
Period
Freq
Rise Time
Fall Time
+Width
-Width
Coupling
DC
BW Limit
OFF
Probe
10X
Invert
OFF
Volts/Div
Coarse
Unit
[V]
CH2
1 = 2.00 V
2 = 2.00 V
3 = 2.00 V
4 = 100mV
H 50.0ms

Fig.9. 20-click device: a) (top) turning the knob one click clockwise; and then b) (bottom) turning one click anticlockwise.

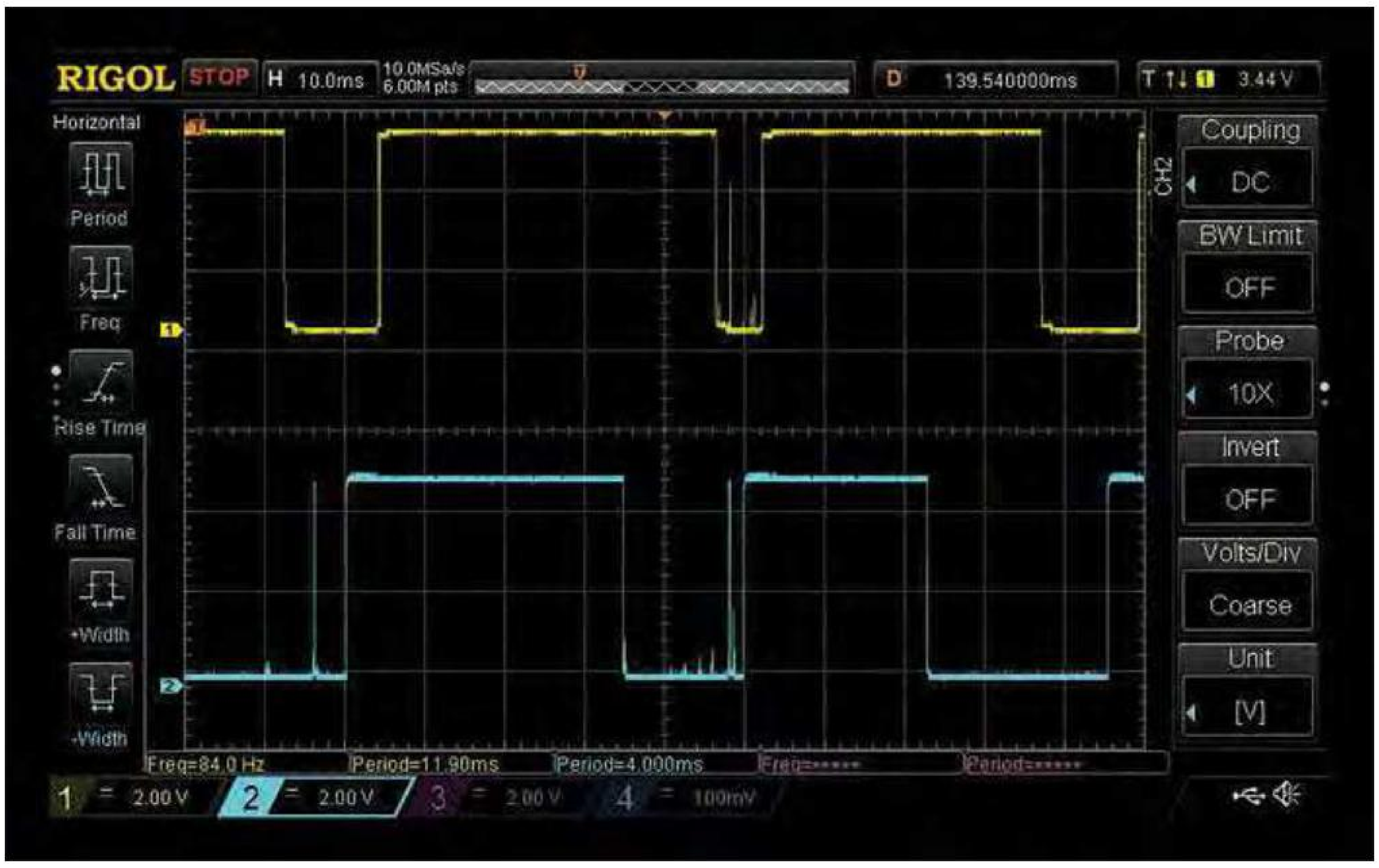

RIGOL
STOP
H 10.0ms
10.0MSa/s
6.00M pts
D 139.540000ms
T 3.44 V
Freq=84.0 Hz
Period=11.90ms
Period=4.000ms
1 = 2.00 V
2 = 2.00 V
3 = 2.00 V
4 = 100mV

Fig.10. The mechanical contacts in rotary encoders can bounce.

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

first for this switch). Similarly, turning the knob one click anticlockwise resulted in the waveforms shown in Fig.9b, with A and B passing through the 01, 00, and 10 states, once again ending up with A and B returning to 11 (A transitioned first for this switch).

All of this obviously gives us a lot to think about. If you weren't aware that these devices can behave in different ways, for example, you might be surprised to discover that for one type of encoder it took two physical clicks for your software to register one count. Contrariwise, a single click on a different type of encoder might cause your software to register two counts.

Bouncy bouncy!

I'm afraid I haven't told you the whole story (I rarely do). The waveforms I've shown thus far have been relatively clean noise-wise, but some of these devices can be incredibly bouncy, and any bouncing increases with the speed of rotation (Fig.10).

In particular, observe the bouncing in the middle of the screen. It's bad enough if the A and B signals are bouncing in isolation, but it can be a pain in the nether regions if they are bouncing together. It's easy to see how someone's software could get confused by this sort of thing.

In fact, thinking about this caused me to pop out to my 2019 Subaru and start playing with the rotary encoder volume control on its radio. When you turn the knob, a graphical display appears on the screen representing the current volume level. Each click of the knob results in a coloured segment being added to or subtracted from the display.

I've never really looked at this closely before. If I turn the knob clockwise the volume goes up; if I turn the knob anticlockwise the volume goes down. However, now that I'm paying close attention, I observe that things are not always as expected. Most of the time, slowly rotating the knob 'forward' one click, for example, causes a segment to be added to the display (and the volume to increase) as expected. However, sometimes we jump 'backward' one 'click equivalent' on the display and the volume goes down, or we jump 'forward' two 'click equivalents' on the display and the volume rises accordingly ('Curiouser and curiouser,' said Alice).

All of this tells me that the people who wrote the software for my car had not performed the same level of evaluations as Joe and your humble narrator. Following on from this, they hadn't come up with the same cunning solution to this problem as have Joe and yours truly. However, that's a story for another day. As always, I welcome your comments, questions, and suggestions.

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ADVERTISING INDEX

CRICKLEWOOD ELECTRONICS 36
ESR ELECTRONIC COMPONENTS 41
HAMMOND ELECTRONICS Ltd 10
iTP . . . . Cover (iv)
JPG ELECTRONICS 72
MICROCHIP . . . . Cover (ii)
PEAK ELECTRONIC DESIGN 25
POLABS D.O.O. 29
QUASAR ELECTRONICS 3
SILICON CHIP 5
STEWART OF READING 55
TAG-CONNECT 41
TERRINGTON COMPONENTS 15

Advertisement offices
Matt Pulzer
Electron Publishing Ltd
1 Buckingham Road
Brighton
East Sussex BN1 3RA

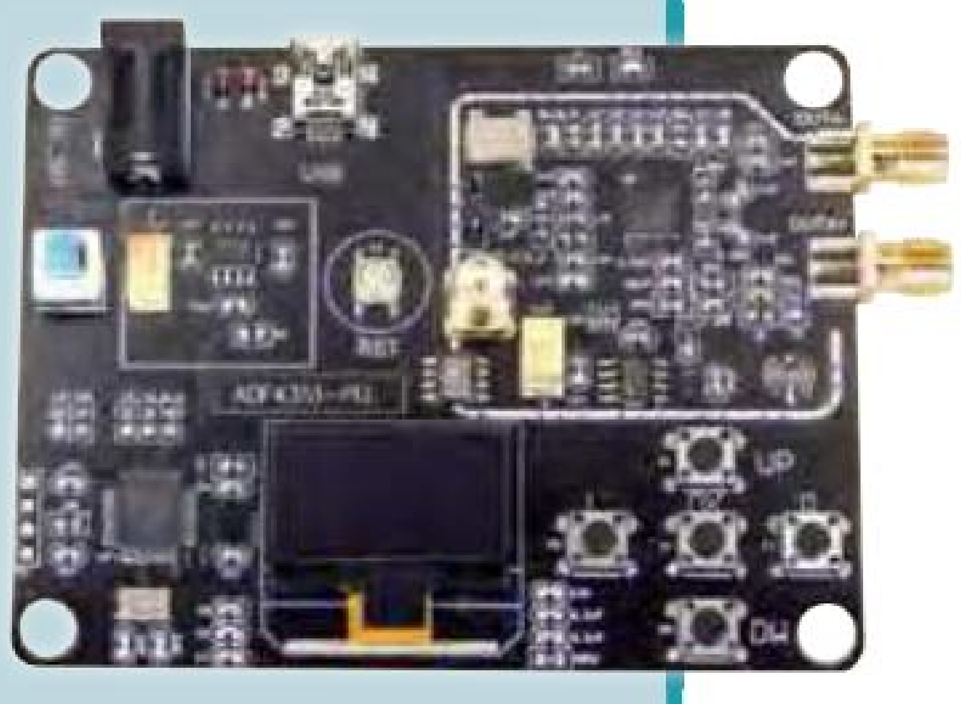
Tel 07973 518682
Email pe@electronpublishing.com
Web www.electronpublishing.com

For editorial contact details see page 7.

Next Month – in the December issue

Hummingbird Audio Amplifier
This miniature audio amplifier delivers up to 60W into 8W or 100W into 4W. It is an ideal building block for multi-channel amplifiers in applications like surround sound or when using an active crossover.

Geekcreit's 35MHz-4.4GHz Signal Generator
This self-contained module is based on the Analog Devices ADF4351 wideband digital synthesiser chip. It has an onboard microcontroller unit, OLED display and pushbuttons to set the desired frequency and adjust the output level. All it needs is a 5V DC power supply.



SMD Trainer Board
Are you interested in learning to solder small surface-mount devices but don't want to ruin an expensive board or chip gaining those skills? This simple Trainer project is a great way to practise soldering a variety of surface-mount devices. If done correctly, you'll be rewarded with a series of LEDs flashing in sequence.

USB Cable Tester – Part 2
We have introduced and described the USB Cable Tester, next month it's time to build and test it.

PLUS!
All your favourite regular columns from *Audio Out*, *Cool Beans and Circuit Surgery*, to *Make it with Micromite*, *Techno Talk* and *Net Work*.

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CH1
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*Prices vary depending on model and specification

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